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Western Pacific Basin

A Climatological Study

Written By:

Mrs. Melody Higdon
Mr. John Louer III
Mr. Robert Lilianstrom
Mr. Virgil Killman
MSgt Don Carey

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Air Force Combat Climatology Center
151 Patton Avenue, Room 120
Asheville, North Carolina 28801-5002

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Robert J. Falvey

ROBERT J. FALVEY, Lt Col, USAF
Chief, Operations Division

John D. Gray

JOHN D. GRAY, GS-13, DAF
Scientific and Technical Information
Program Manager

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13. Abstract: This technical note is a climatological study of the Western Pacific Basin. After describing the geography and major meteorological features of the entire region, the study discusses in detail the climatic controls of each of the Western Pacific Basin's "five zones of climatic commonality." Each "season" is defined and discussed in considerable detail with emphasis on general weather, hazards, clouds, visibility, winds, precipitation, and temperature.

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PREFACE

This study was prepared by the Air Force Combat Climatology Center's Climate Analysis Team (now AFCCC/DOPA) in response to a support assistance request (SAR) from the Air Force Weather Agency, Offutt AFB, Nebraska.

Thanks to all the people in AFCCC's Operational Climatology Branch, who provided the immense amount of data required for the preparation of this regional climatology study. The authors owe sincere gratitude to the technical editors and graphics illustrators, past and present—Mr. Gene Newman, Mr. Mike Jimenez, Technical Sergeant Gina Vorce, and Staff Sergeant Kurt Riley. Without their patience, cooperation and creativity, this project would not have been possible.

Major Malcom Walker
Chief, Climate Analysis Team

INTRODUCTION

Area of Interest. This study describes the topography, climatology, and meteorology of the Western Pacific Basin. The regional has been subdivided into five zones of climatological commonality as depicted in Figure 1-1.

Figure 1-1. Western Pacific Basin. The figure depicts the climatic commonality zones discussed in this regional climatology.

Western Pacific Basin. For the purpose of this study, South Asia has been subdivided into five zones: Sumatra, Java and the Lesser Sunda Islands; Borneo; Celebes, the Molucca Islands, and New Guinea; Philippine Archipelago; and the Western Pacific Ocean Islands.

Sumatra, Java, and the Lesser Sunda Islands. This area includes Sumatra, Java, and all the Lesser Sunda Islands from Bali to Timor.

Borneo. This region, north of Sumatra and Java, includes the whole island of Borneo (includes East Malaysia, Kalimantan, and Brunei), and the Indonesian islands of Anambas and Natuna.

Celebes, the Molucca Islands, and New Guinea. This area includes the Celebes Island group, the Molucca Island group, and the whole island of New Guinea, which is shared between two nations.

Philippine Archipelago. This area includes all the Philippine Islands in three groups. The northern group includes Luzon, the Babuyan Islands, the Batan Islands, and numerous small islands around the larger ones mentioned. The central group includes Mindoro, Palawan, the Visayan Islands, the Romblon Islands, Samar, and numerous islands in the vicinity. The southern group includes Mindanao and numerous small islands as far south as the Jolo Island group.

Western Pacific Ocean Islands. This region includes the deep ocean islands of the western Pacific basin in three groups. The northern group encompasses the Mariana Islands. The central group includes all the islands and atolls east of the Philippines to 165° E and between the equator and 10° N. This incorporates Palau and the Micronesian Islands. The southern group encompasses all the islands between New Guinea and 165° E and between the equator and roughly 12° S. It includes the Solomon Islands, Bougainville Island, New Ireland, and New Britain.

Study Content. Chapter 2 provides a general discussion of the major meteorological features that affect this part of the western Pacific basin. These features include climatic controls, synoptic disturbances and mesoscale and local features. The individual treatments of each region in subsequent chapters discuss how these features uniquely affect that particular region. Meteorologists using this study should read and consider the general discussion in Chapter 2 prior to trying to understand or apply the individual climatic zone discussions in chapters 3 through 7. This is particularly important because this study was designed with two purposes in mind: first, as a master reference for the western Pacific basin; and second, as a modular reference for each region.

Chapters 3 through 7 amplify the general discussions in Chapter 2 by discussing the topography, climate, and meteorology of the zones of climatic commonality shown in Figure 1-1. These chapters provide detailed discussions in the reasonably homogenous zones of climate and meteorology. In mountainous areas, however, weather and climate are not necessarily internally homogenous. Conditions can be distinctly different in two locations which are geographically close yet topographically far apart.

In each region, topography is discussed first (including terrain, rivers and drainage systems, lakes, water bodies, and vegetation). Next, major climate controls, and, if appropriate, special climatic features are described. Then weather conditions for each season is discussed in the following order:

- General Weather
- Sky Cover
- Visibility
- Winds
- Upper-Air Winds
- Precipitation
- Temperature

Conventions. The spelling of place names and geographical features are those used by the National Imagery and Mapping Agency (NIMA). Surface distances and elevations are in feet with conversions to meters or statute miles (miles) with conversions to kilometers (km). Wind speeds are reported in knots. Cloud and ceiling heights are reported in feet. When the term “ceiling” is used, it means 5/8 cloud coverage at and below any level unless otherwise stated. Cloud bases are above ground level (AGL) and tops above mean sea level (MSL) unless specified otherwise. Temperatures are in degrees Fahrenheit (°F) with conversions in degrees Celsius (°C). Wind speeds are in knots. Precipitation amounts are in inches and millimeters (mm) up to 1,000 mm. From that point higher, amounts are in meters. Pressures are given in millibars (mb). Latitude and longitude are listed in degrees north, south, east or west (example: 55° N). Charts are labeled in Universal Coordinated Time (UTC or “Z” (Zulu) time) or in local time (L). Visibility is in statute miles (miles) with conversions to kilometers (km) except for times when visibility is 9,000 meters or below. Then conversions will be to meters. Thunderstorm days are those on which they have been reported. Precipitation days include those with any type of precipitation.

Data Sources. Most of the information used in this study came from two sources. Studies, books, atlases, and so forth were supplied by the Air Force Weather Technical Library (AFWTL). Climatological data came directly from the Air Force Weather Climatic Database.

Related References. This study is certainly not the only source of climatological information for the military meteorologist concerned with South Asia. Staff weather officers and forecasters are encouraged to contact the Air Force Weather Technical Library (AFWTL) in Asheville, North Carolina for more information.

Chapter 2

MAJOR METEOROLOGICAL FEATURES

Sea-Surface Conditions. The western Pacific basin has a maritime tropical climate with considerable cloudiness and precipitation. Temperatures and relative humidity are fairly uniform throughout the year with variations in the higher elevations (Figure 2-1). Two of the major factors for this are the region's close proximity to the equator and the vast ocean expanse within and around it. Since the region lies within 20 degree's latitude of the equator, the daily influence of the sun's insolation is pronounced. As a result, sea-surface temperatures are fairly stable throughout the year (Figure 2-2a-d).

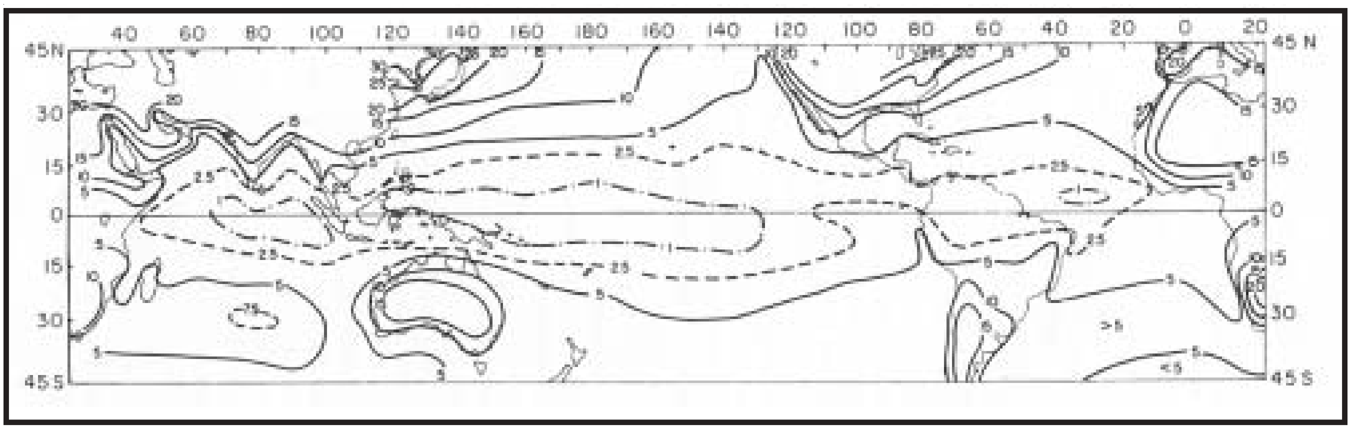

Figure 2-1. Mean Annual Temperature Range (°C) Near Sea-Level. Most of the Western Pacific Basin has a mean annual temperature range of less than 2.5° C. (From Riehl, 1979)

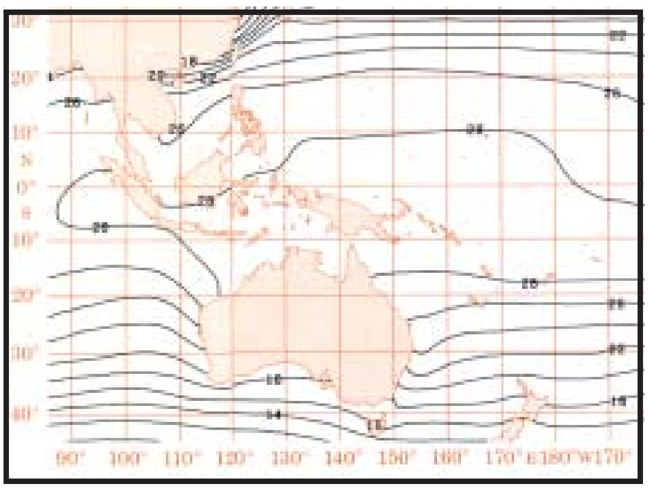

Figure 2-2a. Mean January Sea-Surface Temperature (° C). (Adapted from NAVAIR 50-1C-65, Vol. IX, 1965)

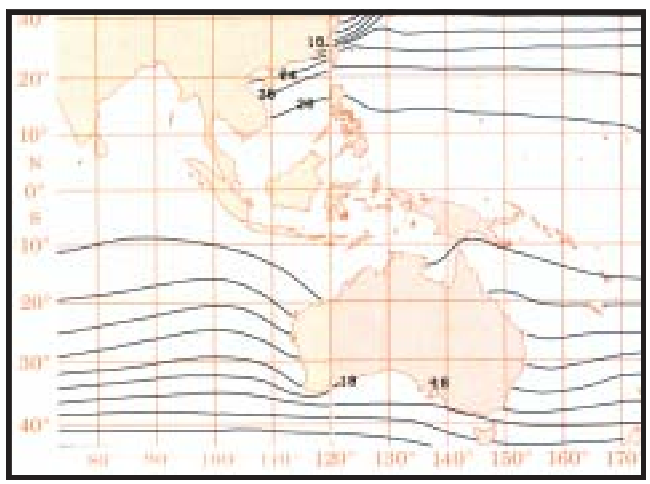

Figure 2-2b. Mean April Sea-Surface Temperature (° C). (Adapted from NAVAIR 50-1C-65, Vol. IX, 1965)

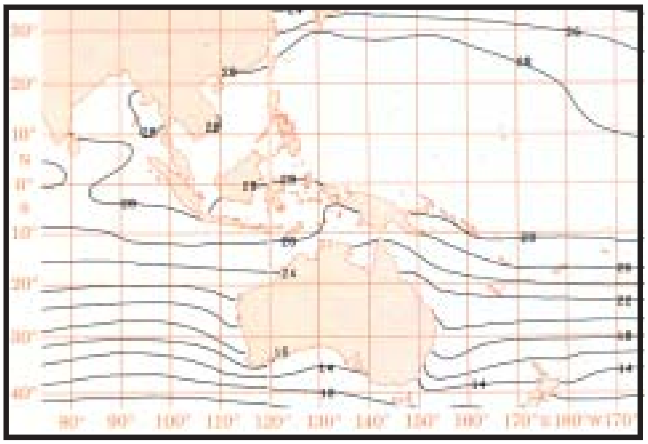

Figure 2-2c. Mean July Sea-Surface Temperature (° C). (Adapted from NAVAIR 50-1C-65, Vol. IX, 1965)

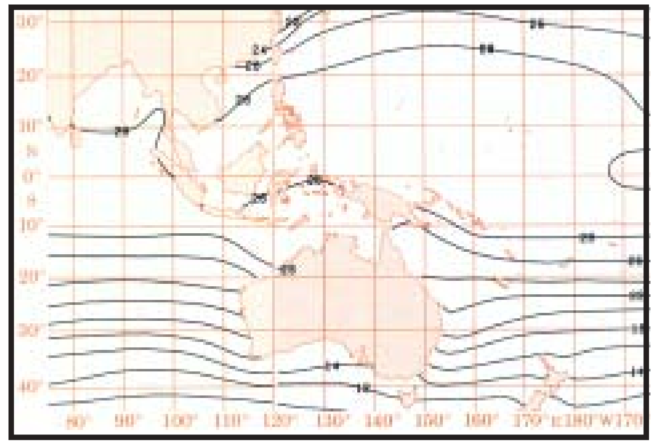

Figure 2-2d. Mean October Sea-Surface Temperature (° C). (Adapted from NAVAIR 50-1C-65, Vol. IX, 1965)

Ocean Currents. Currents play a significant role in the stability of the sea-surface temperatures. The two major currents, the North and South Equatorial currents, flow within 20 degrees latitude of the equator (Figure 2-3). Since they move parallel to the equator, the sun constantly heats the water as it moves from its source region into the western Pacific basin.

Maritime Pressure Features. The features include the North Pacific high, the South Pacific high, and the South Indian Ocean high (Figure 2-4a-d).

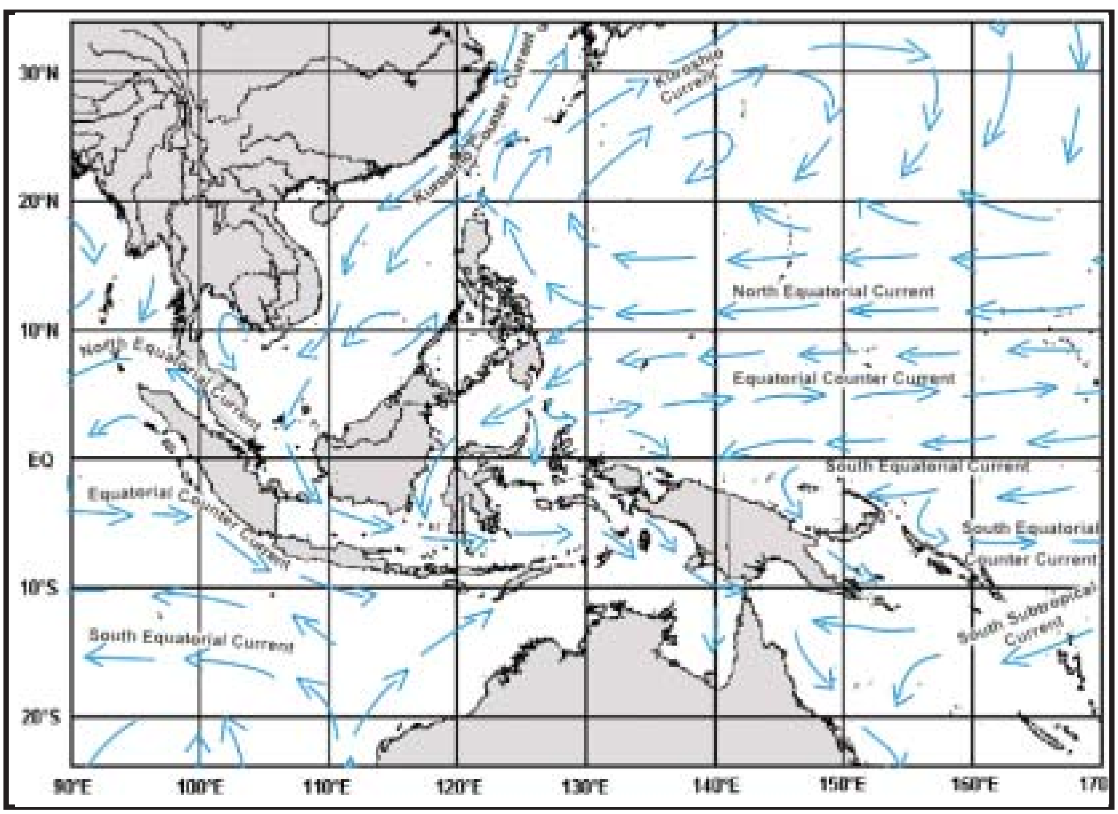

Figure 2-3a. Ocean Currents during February. Large arrows indicate prevailing wind direction. (Traxler, et al, 1997 from Wells, 1986)

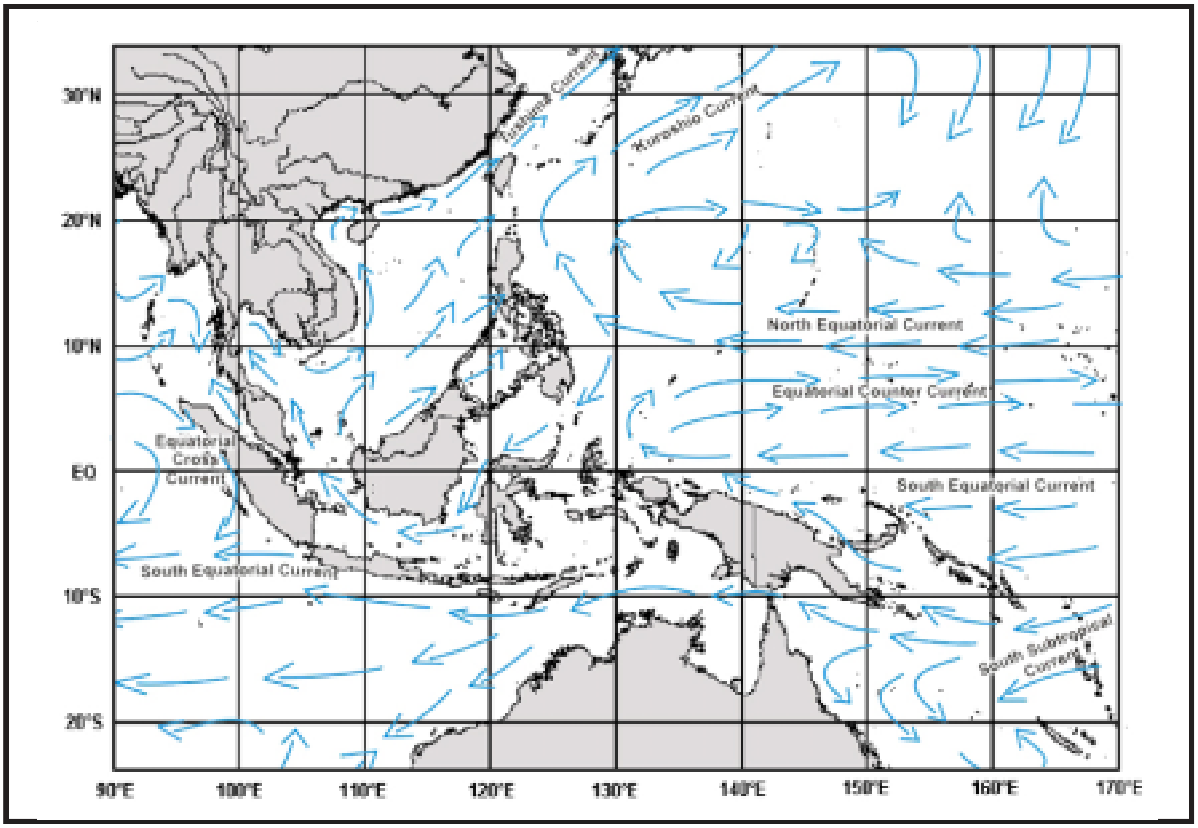

Figure 2-3b. Ocean Currents during August. Large arrows indicate prevailing wind direction. (Traxler, et al, 1997 from Wells, 1986)

North Pacific High. This subtropical high, centered off the North American coast, is farthest north and west in July (Figure 2-4c). In January, it forms a ridge near 25° North. The ridge is near 35° N in July and extends westward into the South China Sea. The position of this high is linked to the movement of the Near Equatorial Trade Wind Convergence (NETWC) and to oscillations in convective activity. On its southern side, it initiates the North Pacific trade winds that dominate the northeast monsoon between cold air surges from the Asiatic high. Between September and November, the high retreats southward very slowly over the warm South China Sea and western Pacific. This allows tropical disturbances to develop well into the northeast monsoon season. During the northeast monsoon, the North Pacific high oscillates between a shallow and a deep flow pattern. Each pattern lasts about 10 days and causes fluctuations in the monsoon. This is part of a phenomenon known as the low frequency oscillation. When the high is shallow, the 200-mb ridge is not evident. Strong upper-level westerlies prevail to south of the equator, while easterly winds predominate at the 700-mb level south of the high. East-moving tropical waves tend to develop while tropical cyclones are rare in the Northern Hemisphere; however, when the high is deep, a strong ridge can be found at 200 mb while the equatorial westerlies dominate at the 700-mb level south of 10° North. Tropical cyclones develop between the northeast trade winds and the westerlies. If, during the southwest monsoon, the North Pacific high lies further west than normal, a *"monsoon break"* occurs. These breaks can lead to a significant increase in rainfall over the equatorial western Pacific.

South Pacific High. This is the Southern Hemispheric counterpart to the North Pacific high. Mean central pressure ranges from 1018 mb in March to 1026 mb in October. The cell migrates from 33° S, 92° W in January to 26° S, 98° W in July. It ridges

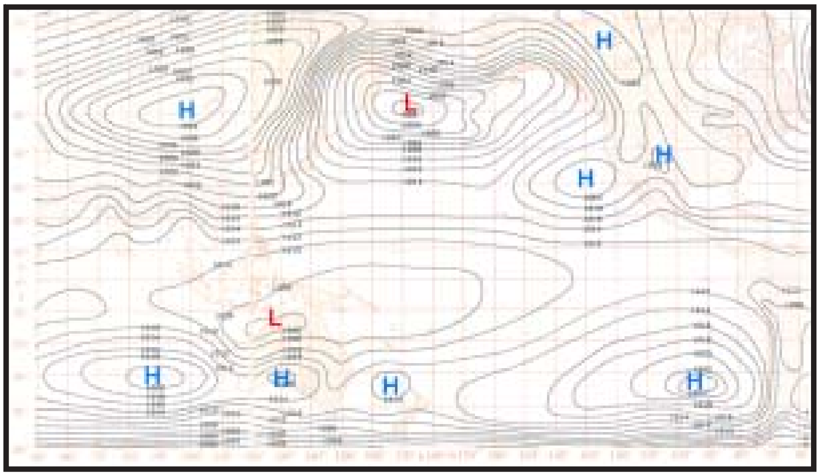

Figure 2-4a. Mean January Sea Level Pressure (mb). (From NAVAIR 50-1C-65, Vol. IX, 1965)

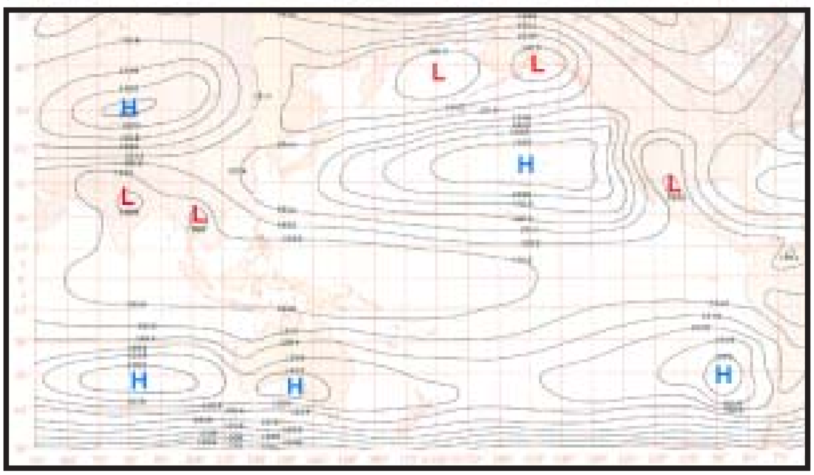

Figure 2-4b. Mean April Sea Level Pressure (mb). (From NAVAIR 50-1C-65, Vol. IX, 1965)

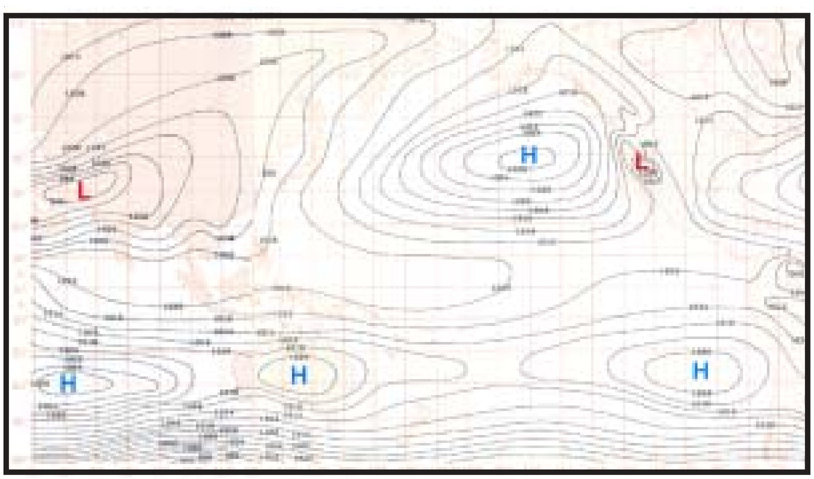

Figure 2-4c. Mean July Sea Level Pressure (mb). (From NAVAIR 50-1C-65, Vol. IX, 1965)

westward towards Australia (Figure 2-4c), especially during the Southern Hemisphere summer. The high slopes equatorward with height. Outflow from the South Pacific high forms the South Pacific trade winds. These southeasterly winds affect the western Pacific basin during the southwest monsoon. They are not very strong and only extend to about 8,000 feet MSL. The strength and position of the South Pacific high displays a cycle similar to that of the North Pacific high. This affects tropical cyclone development and the position of the NETWC.

South Indian Ocean (Mascarene) High. The mean central pressure of this high ranges from 1021 mb in January to 1026 mb in July though the pressure can exceed 1040 mb during Southern Hemisphere winter. Annual movement is east-west from 30° S, 87° E in January to 29° S, 65° E in July (Figure 2-4c). The high slopes equatorward and westward with height. The high's outflow helps form the Indian southwesterlies, a cross-equatorial flow that drives southwest monsoonal flow. Its large east-west movement causes seasonal variations in the strength of the equatorial westerlies.

Aleutian Low. The Aleutian low sits over the far North Pacific and affects the western portion of the western Pacific basin during the northeast monsoon. It reaches maximum strength in January with a central pressure near 996 mb (Figure 2-4a). The Aleutian low acts with the Asiatic high to establish a strong pressure gradient over the western Pacific Ocean. The strength of this pressure gradient is directly related to the strength of the northeast monsoon.

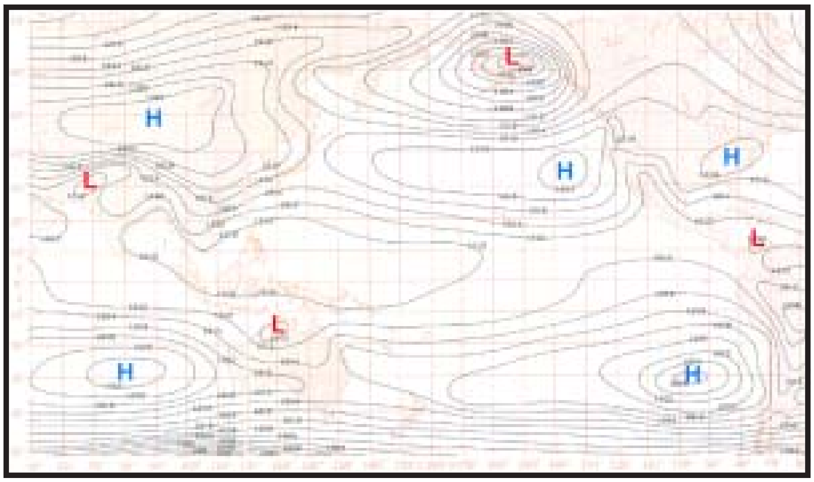

Figure 2-4d. Mean October Sea Level Pressure (mb). (From NAVAIR 50-1C-65, Vol. IX, 1965)

West China Trough. The Asiatic high tends to form two ridges—one pointing southeastward to the Chinese coast and Taiwan, the other stretching southwestward along the eastern Indian coast and merging with the Indian high. The broad west China trough lies between these two ridges from central Myanmar to southwestern China. The lee side effect of the Tibetan Plateau intensifies this trough. Active cold surges often occur when this trough is weak.

Continental Pressure Features. These features include the Asiatic high, the Australian high, the west China trough, and several heat lows.

Asiatic High. The Asiatic high is a strong, but shallow high-pressure cell that dominates the Asian continent from late September to late April. It is the strongest cold anticyclone in the Northern Hemisphere, but it rarely extends above the 850-mb level. It is normally overlaid by westerlies aloft. The mean central pressure is strongest (1038 mb) in January when the high is centered over western Mongolia (Figure 2-4a). The Asiatic high is created and supported mainly by radiational cooling, though migratory Arctic air masses temporarily intensify it. The central pressure occasionally exceeds 1050 mb for up to 3 days; the highest recorded pressure is 1083 mb. It works with the Aleutian low to create a strong pressure gradient over the western Pacific Ocean. Variations in the high result in a 10- to 12-day cycle in the strength of the northeast monsoon.

Australian High. This thermal high is present during the Southern Hemisphere winter. It is strongest in July, when it is near 28° S, 128° E with a central pressure of about 1022 mb (Figure 2-4c). It is neither as strong or as persistent as the Asiatic high and is crossed regularly by disturbances and migratory highs.

Australian Low. This thermal low develops during the Southern Hemisphere summer. It strengthens the northeast monsoon by increasing the pressure gradient between Asia and Australia and by helping draw the NETWC south. Its mean January position is 15° S, 130° E, with a mean pressure of 1006 mb (Figure 2-4a).

Asiatic (or Pakistani Heat) Low. From May to early October, this low anchors the eastern end of a broad, low-level thermal trough that extends from northwestern India across Pakistan, Iran, Saudi Arabia, and into the Sahara. The low, normally cloud-free, is strongest in July, when its central pressure averages 994 mb. Its mean position in July is near 32° N, 65° E (Figure 2-4c), and it anchors the western end of the NETWC.

Indian High. This thermal high occasionally develops over India during the northeast monsoon season because of cold surges from the western Himalayas. Even at its strongest, it is relatively weak. Since its intensity and position are highly variable, its presence is not evident in the mean charts shown in Figure 2-4a-d. When the high is unusually strong, it produces a north-northwesterly flow over western Indonesia. The wind is quickly modified by the Indian Ocean. The air stream seldom passes south of 5° North.

General Circulation. The large-scale circulation regime is fairly complex. Most of the region falls within the world's monsoon zone (Figure 2-5), and it is influenced by the outflow of both the North and South Pacific highs and the South Indian Ocean high. Figure 2-6 is a representation of the circulation of the western Pacific basin.

Monsoon Climate. During the Northern Hemisphere winter, the warm oceanic ridge and the Asiatic high form a continuous belt of high pressure. In Northern Hemisphere summer, the Asiatic low replaces the Asiatic high of Northern Hemisphere winter. This seasonal reversal of the pressure gradient gives rise to the northeast and southwest monsoons. The term "monsoon" (from the Arabic "mawsim", or "season") is commonly applied to those areas of the world where there is a seasonal reversal of prevailing winds, but the accepted definition of a monsoon climate includes four criteria:

- Prevailing wind direction shifts by at least 120 degrees between January and July.
- The average frequency of prevailing wind directions in January and July exceeds 40 percent.
- The mean resultant winds in at least one of the months exceeds 6 knots.
- Fewer than one cyclone-anticyclone alternation occurs every 2 years in either month in a 250 x 250 NM (500 x 500 km) square.

Equatorial Trough (ET). Also called the monsoon trough or near-equatorial trough (NET), the ET marks the dividing line between the winds of the northeast and the southwest monsoon (see Figure 2-7). The ET, also called the intertropical convergence zone (NETWC) or the meteorological equator, results from the convergence of the outflows from Northern and Southern Hemisphere subtropical highs. The slopes of these boundaries are not uniform with height but fluctuate with small changes in density and wind speed. The ET's annual movement lags behind the sun by two months (see Figure 2-8) because atmospheric heating does not end with the solstice. The highest temperatures are reached a month later over large continental areas, and two months later over oceans and in the upper air.

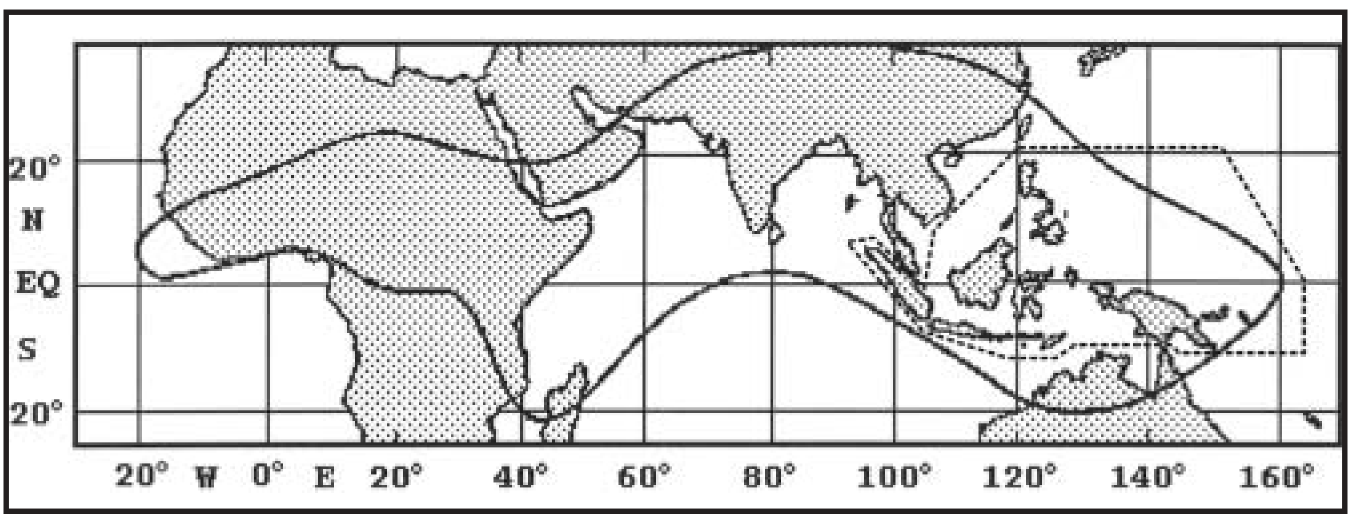

Figure 2-5. Monsoon Region. Area satisfying Ramage's monsoon criteria is enclosed by the solid line. The area delineating the Western Pacific Basin is enclosed by a dashed line. (Adapted from Ramage, 1995)

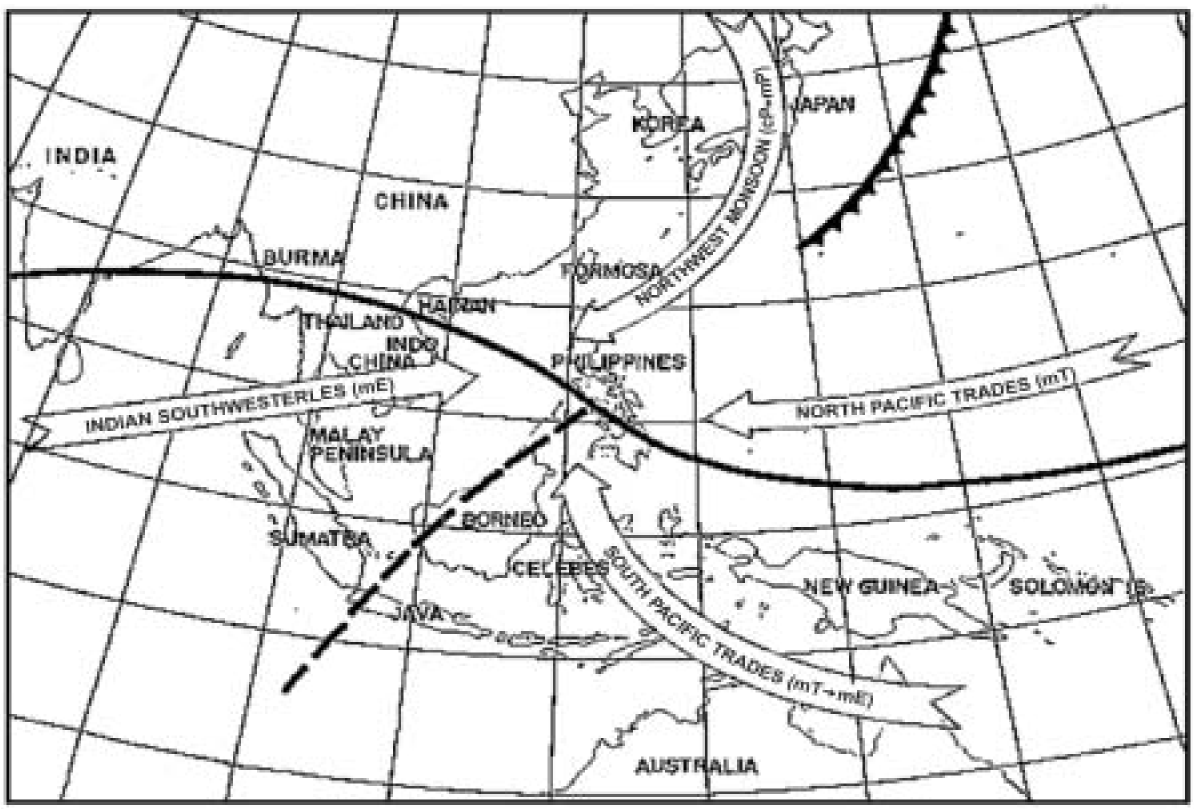

Figure 2-6. Western Pacific Basin Circulation. Schematic diagram depicting the major wind systems affecting the Western Pacific Basin during the year. The Indian southwesterlies are an air stream that is part of the summer southwest monsoon. The solid west to east line depicts the Equatorial Trough (ET). The dashed line depicts the southern ET, also known as the Southern Near-Equatorial Trough (SNET), that forms between the South Pacific trades and the Indian southwesterlies. (From Estoque, 1956)

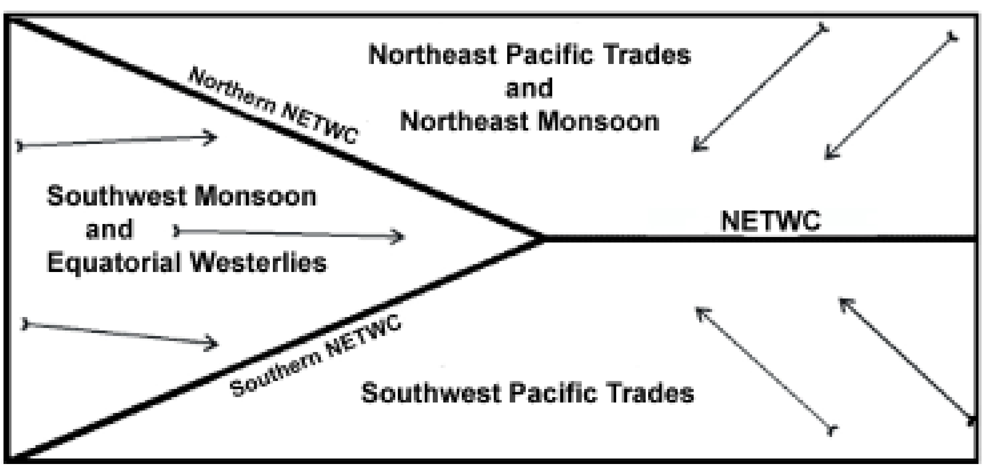

Figure 2-7. Schematic Representation of the ET over the Western Pacific Basin. (From Air Weather Service, 1997 adapted from Watts, 1955)

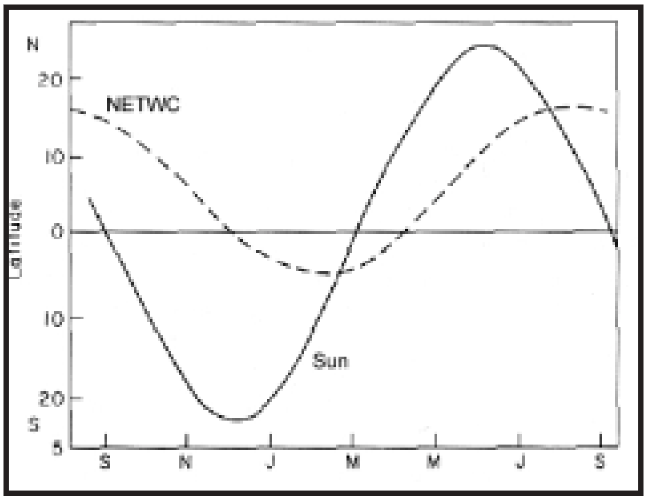

Figure 2-8. Annual Movement of Sun's Zenith Position Versus the ET. (Riehl, 1979)

The ET exists year-round between the trade winds and the equatorial westerlies in the Indian Ocean. It is produced by convergence of the outflows from the North Pacific high and the South Indian Ocean high. The ET is evident up to the 300-mb level. Its northward movement is more gradual than its southward movement. From March to May, as transitory low-pressure systems temporarily weaken the Asiatic high, the ET moves gradually northward in brief 1- to 3-day surges. Northward shifts are usually about 55 miles (90 km) each, but the ET has moved as much as 95 miles (150 km) in 24 hours. Surges are strong during March since the Asiatic high is still strong, but they become much weaker and more variable in April and May. The ET reaches its northernmost position in August. Between July and September, the eastern end of the ET is pulled into the Asiatic heat low, and it gets lost in the rugged terrain. The ET retreats southward during the fall, marking the onset of the northeast monsoon.

During the northeast monsoon, the ET sometimes becomes active as weak disturbances pass westward along it; this brings rainfall to areas south of 10° N. Rainfall can be heavy. These disturbances can couple with eastward-moving disturbances along the subtropical jet to create broad areas of rainy weather. Within the ET itself, there are convergence zones or vortices, possibly from disturbances within the trades, that control convection. When strong, these vortices extend up to 500 mb. Figure 2-9 shows the precipitation associated with vortices along the ET (also called NNET) and South Indian Ocean Trough (SIOT), also called SNET. These patterns move westward within the trough boundaries.

This area of the world is unique in that it has two configurations of the ET. West of 140° E, there is a monsoon trough while east of 140° E, the ET is known as the Near Equatorial Tradewind Convergence (NETWC). See Figure 2-7.

West of 140° E, the ET (monsoon trough) exists year-round between the trade winds and the equatorial westerlies in the Indian Ocean. It is produced by convergence of the outflows from the North Pacific high and the South Indian Ocean high. The ET is evident up to the 300 mb level. Its northward movement is more gradual than its southward movement. From March to May, as transitory low-pressure systems temporarily weaken the Asiatic high, the ET moves gradually northward in brief 1-3-day surges. Northward shifts are usually about 55 miles (90 km) each, but the ET has moved as much as 95 miles (150 km) in 24 hours. Surges are strong during March since the Asiatic high is still strong, but they become much weaker and more variable in April and May. The ET reaches its northernmost position in August. Between July and September, the eastern end of the ET is pulled into the Asiatic heat low, and it gets lost in the rugged terrain.

The ET retreats southward during the fall, marking the onset of the northeast monsoon. During the northeast monsoon, the ET sometimes becomes active as weak disturbances pass westward along it; this brings rainfall to areas south of 10° N. Rainfall can be heavy. These disturbances can couple with eastward-moving disturbances along the subtropical jet to create broad areas of rainy weather. This phenomenon causes Indonesia to experience the wet season from December through February. Within the ET itself, there are convergence zones or vortices, possibly from disturbances within the trades, that control convection. When strong, these vortices extend up to 500 mb. The

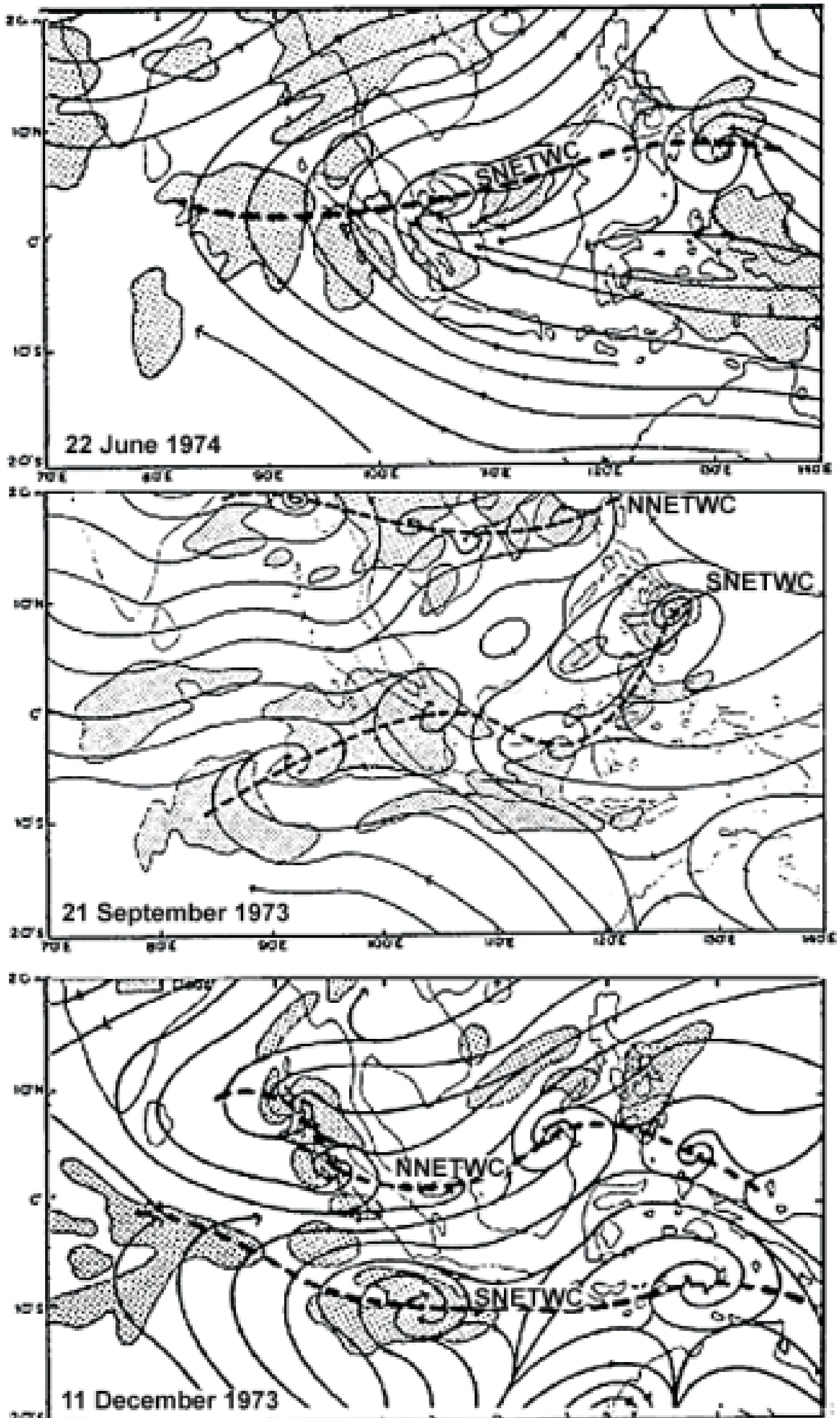

Figure 2-9. Surface Streamline Charts. The charts show vortices and precipitation (shaded areas) along the NETWCs. (From Chen & Choon, 1988).

mountains on Sumatra and Borneo help form the convergence zones by turning the northeasterly flow cyclonically.

South Indian Ocean Trough (SIOT). This feature forms during Northern Hemisphere summer between the Indian Ocean high and the Australian high. The SIOT keeps the southwestern portion of the western Pacific basin rainy during the southwest monsoon, even though the NETWC is far to the north. The strength of the SIOT seems to vary inversely with that of the NETWC; when one is strong, the other is weak. When active, each is evident on streamline charts as a series of quasi-stationary vortices or closed lows. These lows tend to form on the lee side of hills or over areas of high temperatures. Although their movements usually generate heavy convection and rainfall, the specific weather they produce is very sensitive to changes in the boundary's slope. There is rarely a continuous line of clouds and precipitation along the trough axis.

South Pacific Convergence Zone (SPCZ). Formation of the SPCZ results from the convergence of air flow from both the South Pacific high and the South Indian Ocean high. It is reinforced by migratory high pressure systems moving eastward from the Australian continent. The SPCZ is a northwest-southeast oriented cloud region over the southwestern Pacific Ocean. It is a zone of convergent trade-wind easterlies in the Australia and New Zealand region and is a semipermanent feature. The SPCZ branches off the NETWC near Indonesia and extends southeasterly across the southern Pacific (Figure 2-10). It shows little seasonal change in location or frequency of occurrence. Moderate turbulence, frequent moderate or heavy rain and cumulonimbus clouds with tops above 30,000 feet (9,100 meters) are associated with the SPCZ. Dense altostratus layers to 20,000 feet or more are also common. See Figure 2-11a-j for the mean monthly positions of the NETWC.

Northeast Monsoon. The northeast monsoon occurs when the NETWC migrates south during Northern Hemisphere winter. Its air flow originates in the cold Asiatic high and follows an anticyclonic path across Japan towards the western Pacific Ocean. It is a

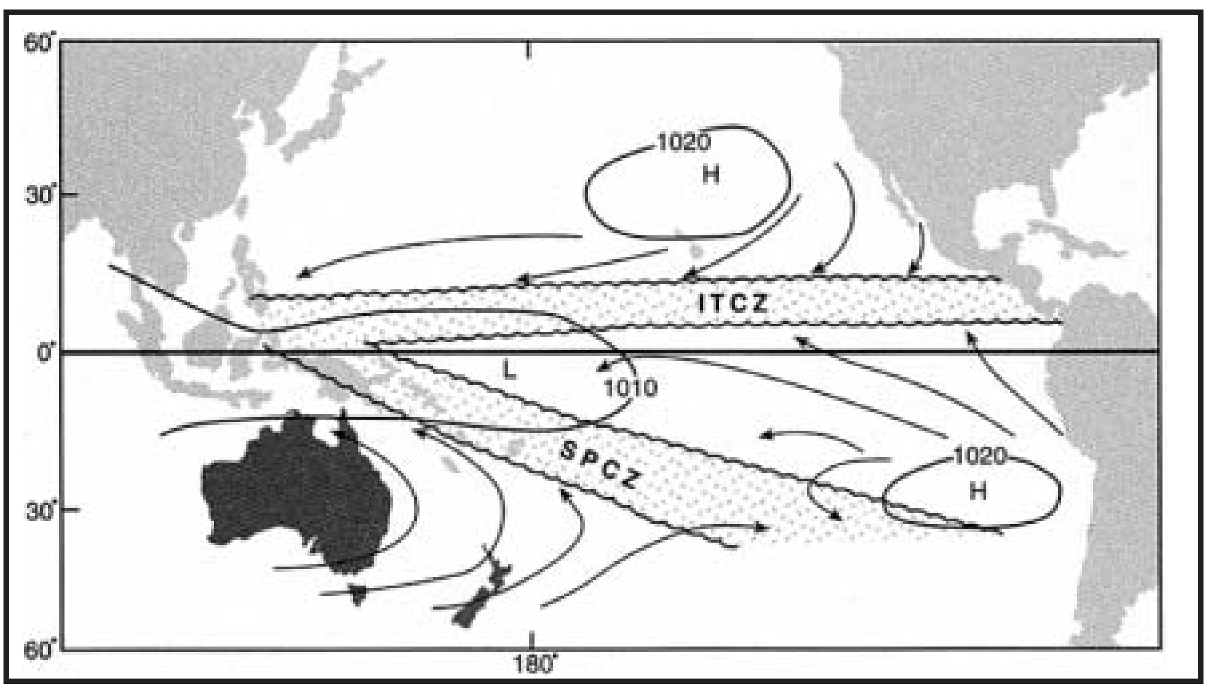

Figure 2-10. South Pacific Convergence Zone. The figure shows the relationship between the South Pacific convergence zone and the ITCZ (NETWC). (From Chen & Choon, 1988).

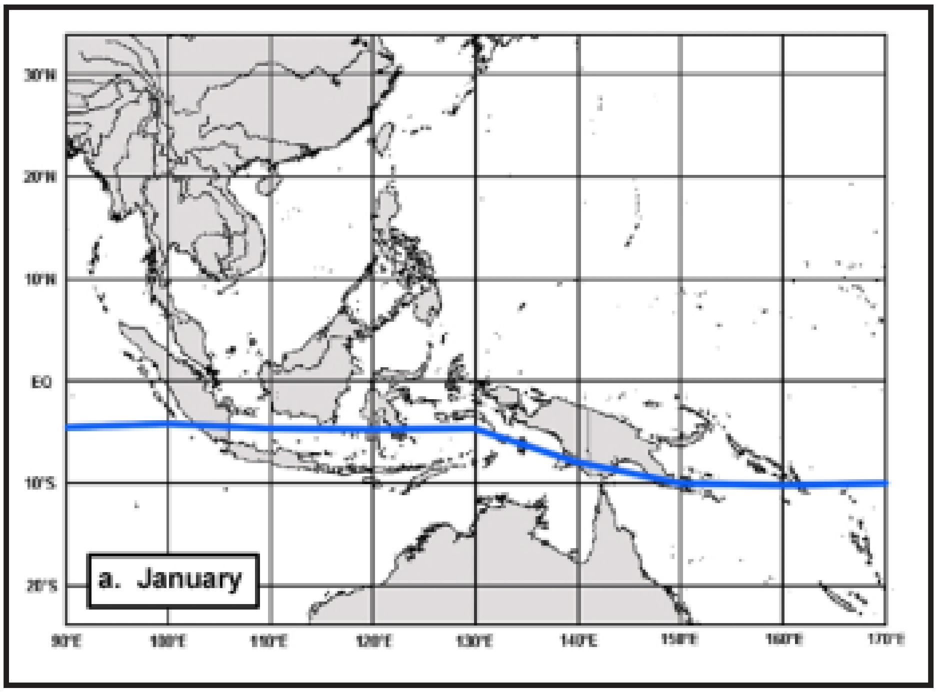

Figure 2-11a. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

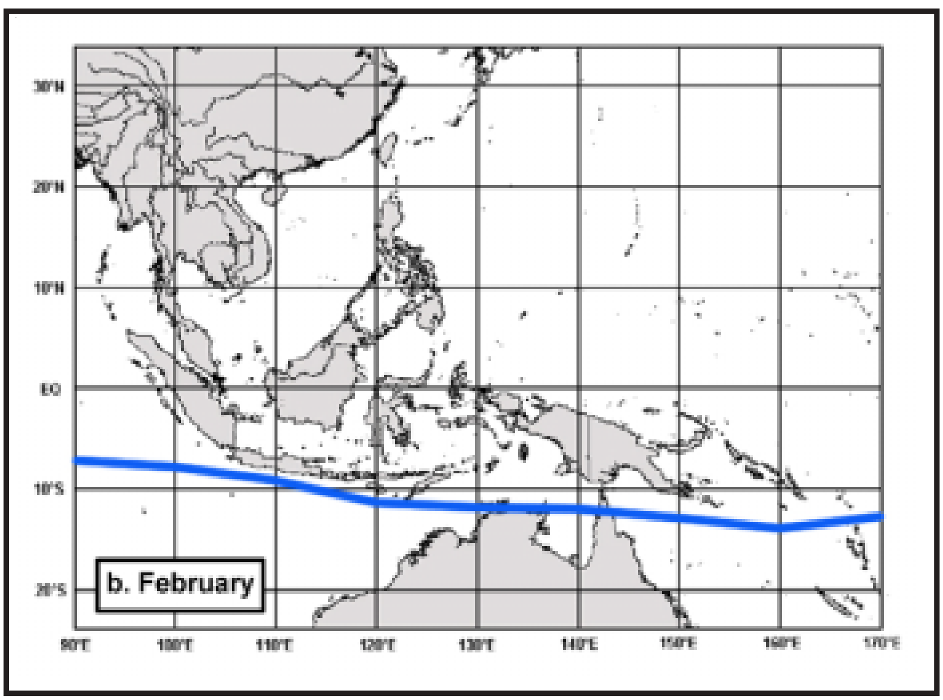

Figure 2-11b. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

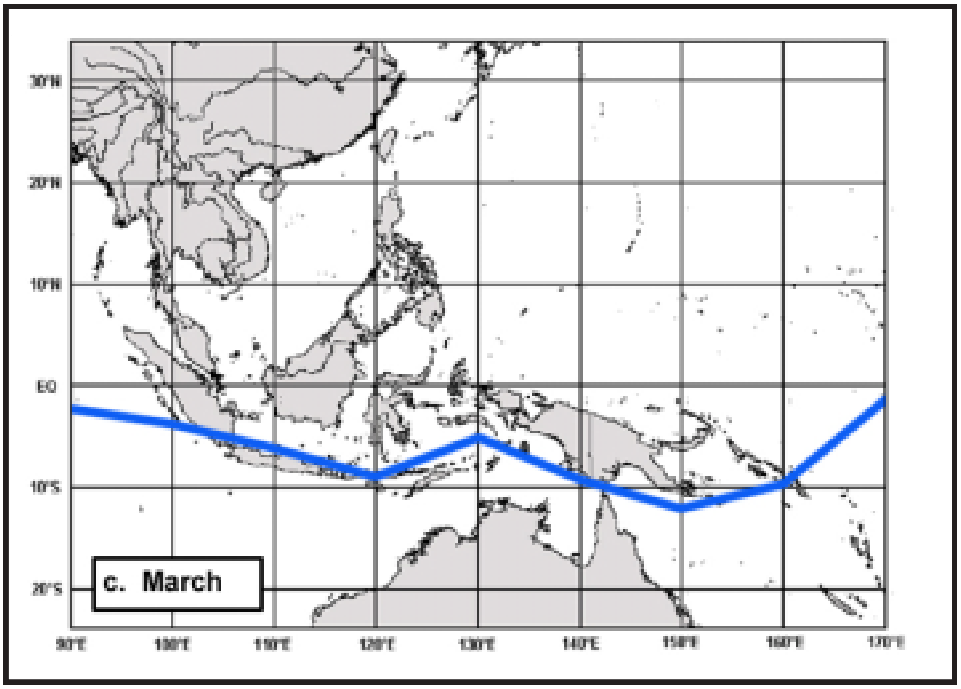

Figure 2-11c. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

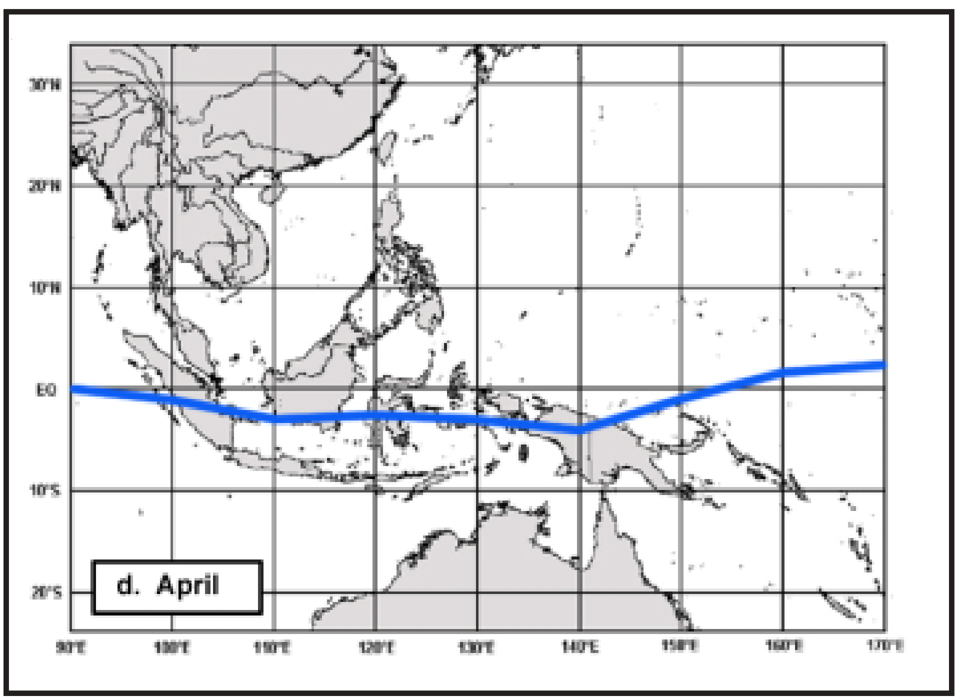

Figure 2-11d. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

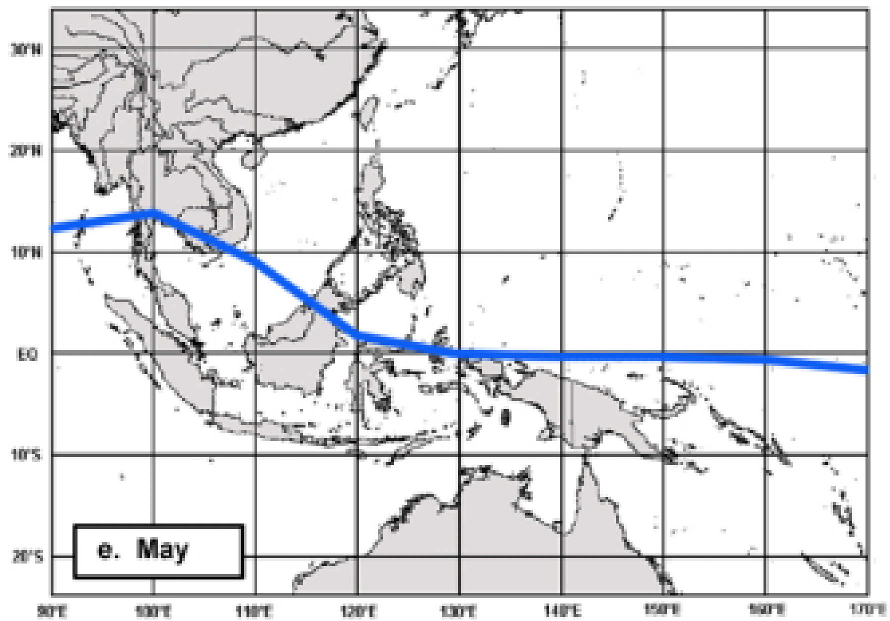

Figure 2-11e. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

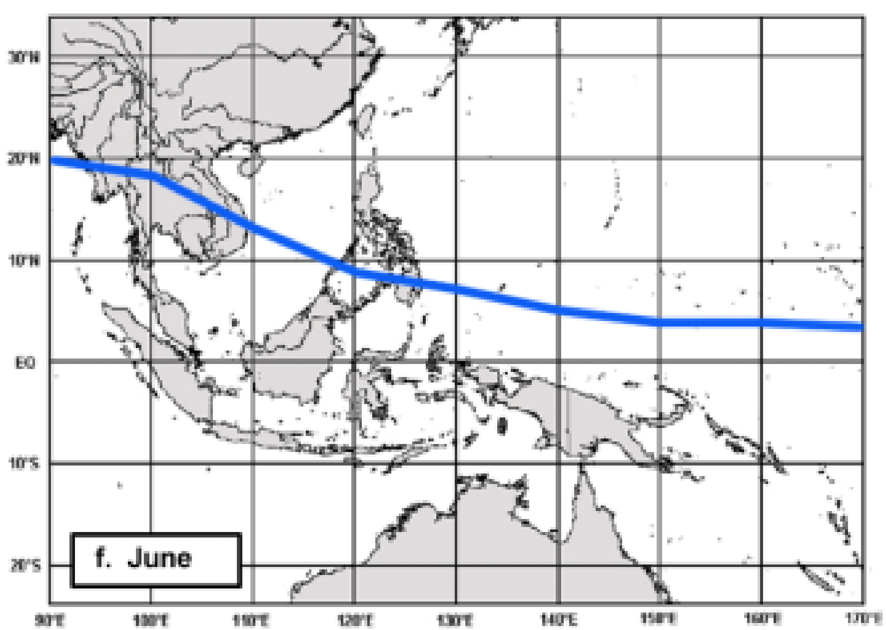

Figure 2-11f. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

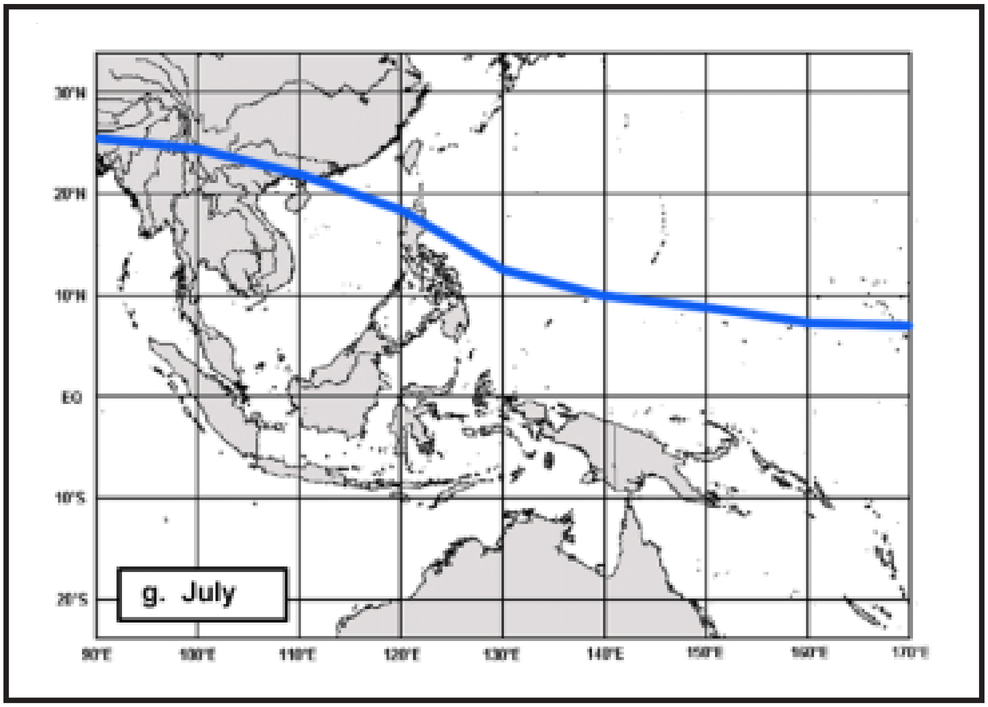

Figure 2-11g. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

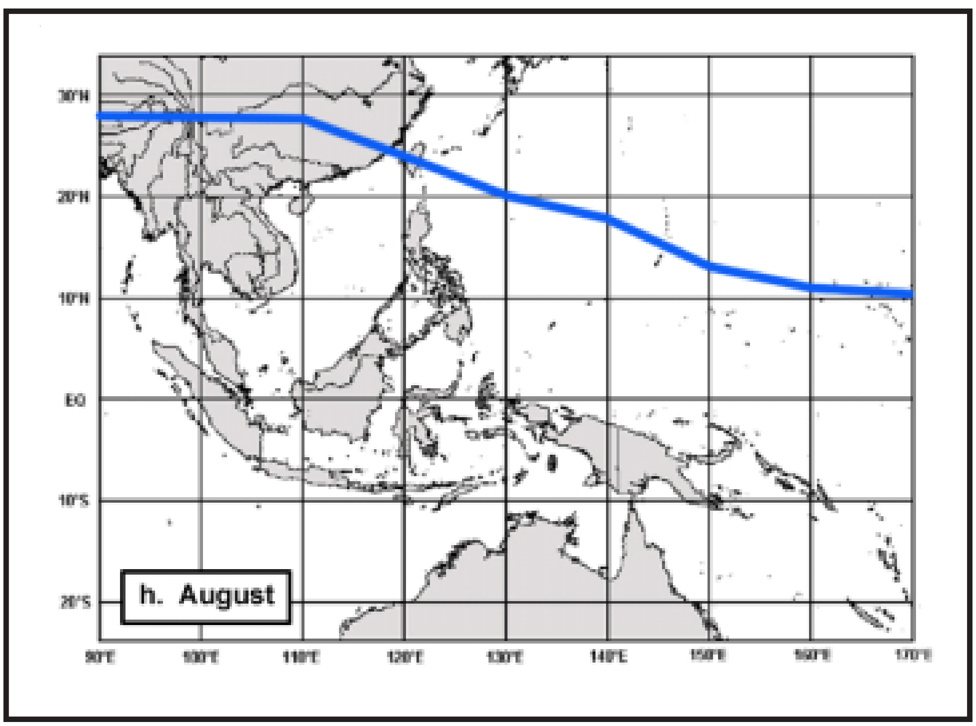

Figure 2-11h. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

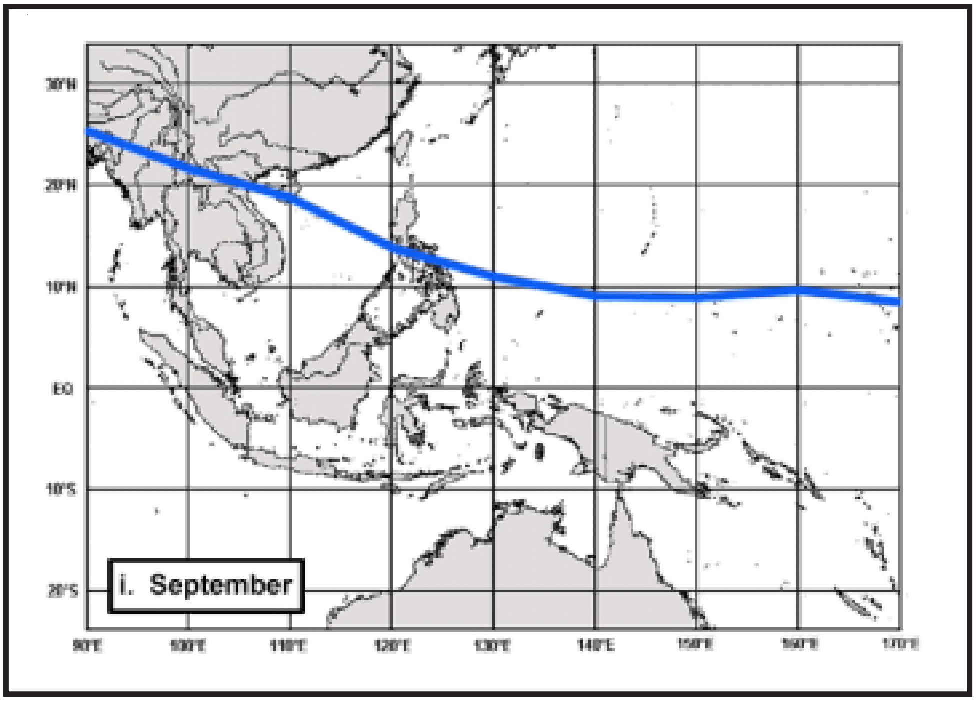

Figure 2-11i. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

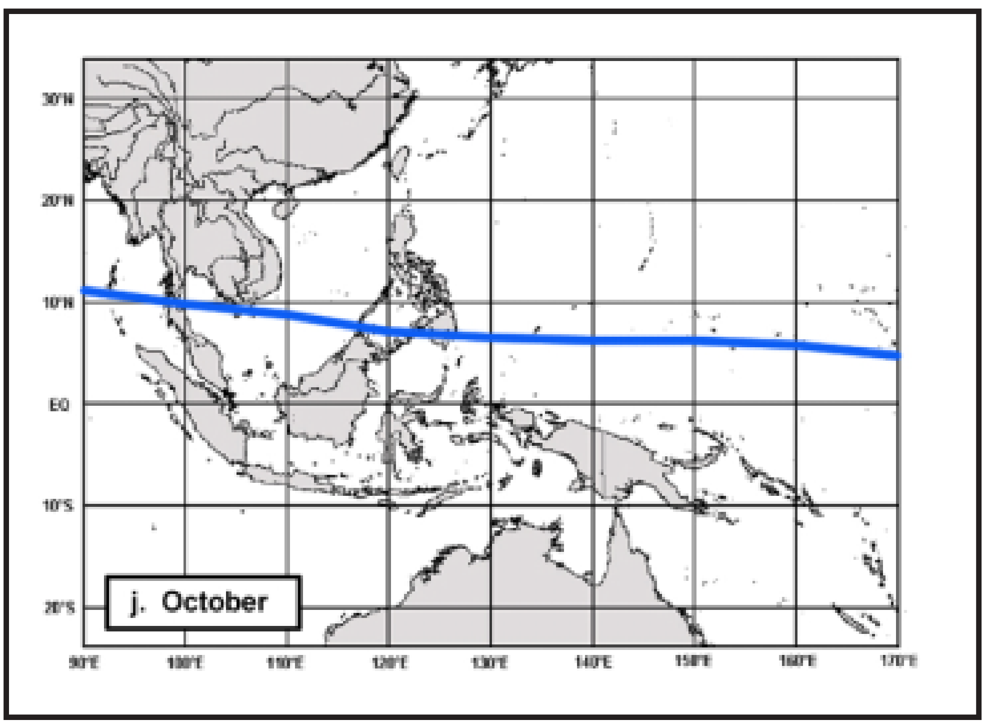

Figure 2-11j. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

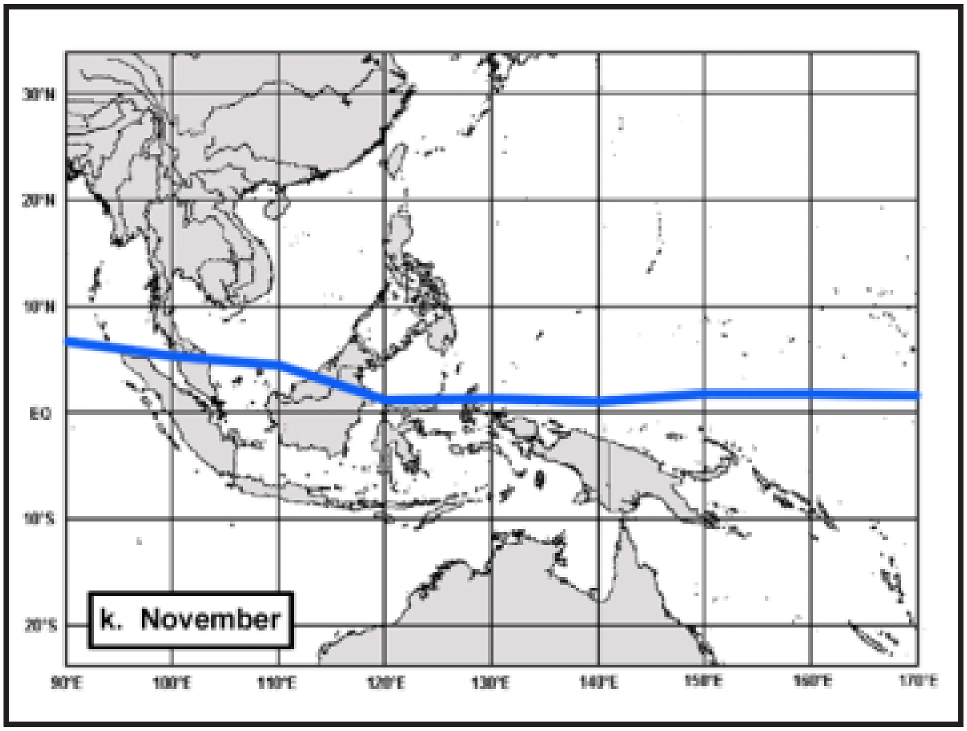

Figure 2-11k. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

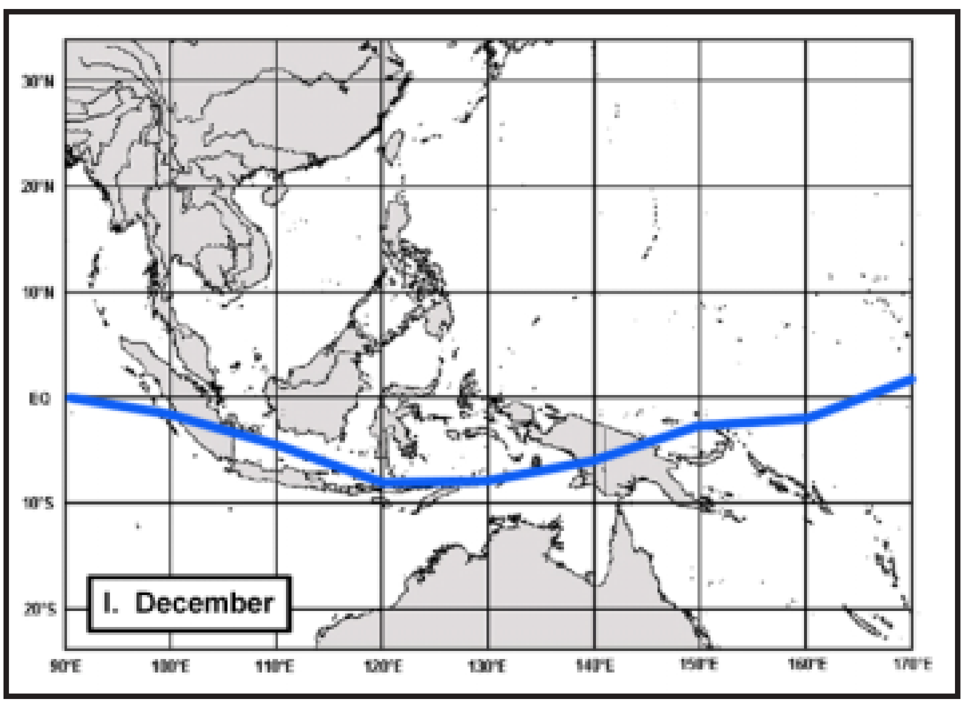

Figure 2-11l. Mean Positions of the Near Equatorial Trade Wind Convergence (NETWC) (From Estoque, 1956: Atkinson and Sadler, 1970).

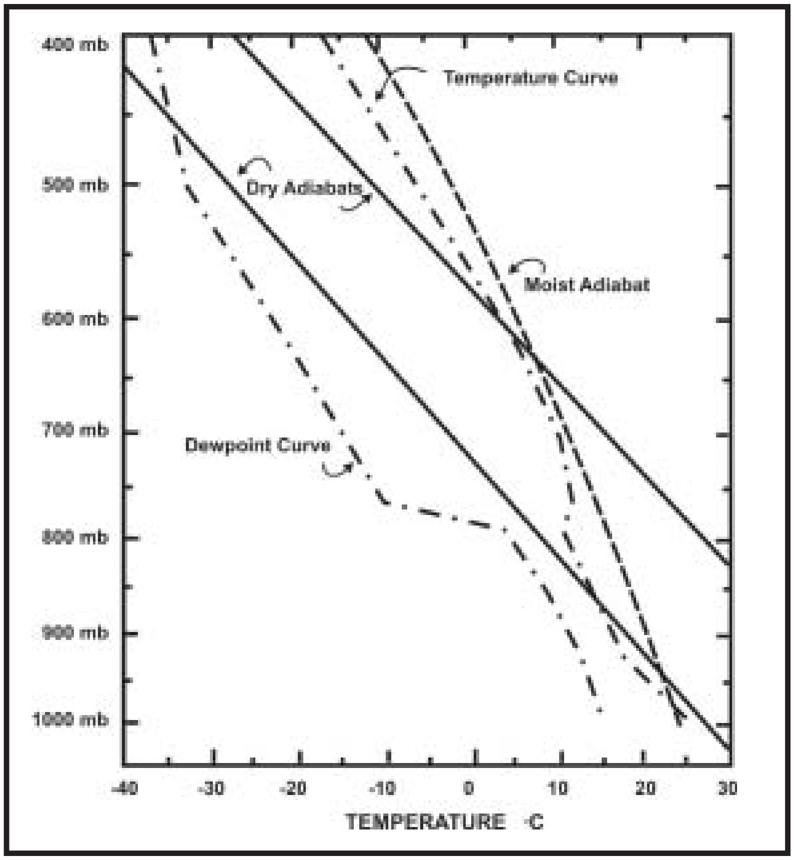

Figure 2-12. Typical Sounding in the Northeast Monsoon over Central Philippines. The monsoon extends from the surface up to about the 800-mb level. A slight temperature inversion exists at the height of the monsoon. Drier air from the Asian mainland is present above the inversion (From Estoque, 1956).

predominately cold, dry, stable, continental polar air stream near its source. As the air stream flows toward the tropics, it rapidly transforms into modified maritime polar, then into maritime tropical air. By the time the air stream reaches 15° N, the surface temperature warms to 77°F (25°C), while the mixing ratio increases to 12 grams per kilogram. This transformation is very rapid (2-4 days). Outbreaks of the northeast monsoon occur about once every six days during the Northern Hemisphere winter. They are linked to the strengthening of the Asiatic high and the consequent establishment of a strong pressure gradient along the southeast China coast. The strengthening of this pressure gradient produces an abrupt increase in the intensity of the low-level northeasterly flow between Taiwan and northwest Borneo. The outbreaks are shallow, rarely over 8,000 feet thick and are usually confined to the surface layers (Figure 2-12). The northeast monsoon is overlain by a deep flow of dry westerlies aloft over the northern regions of the western Pacific basin. Further south and east, it is overlain by the North Pacific trades. The northeast monsoon is characterized by a heavy stratocumulus cloud deck and heavy drizzle over the South China Sea north of 10° N. The skies above the cloud deck are usually clear if the dry westerlies prevail aloft. If the North Pacific trades prevail above the cloud deck, middle and high clouds are observed. In the equatorial regions, thunderstorm activity is initiated or enhanced by the northeast monsoon, usually within 48 hours after the surge begins.

Southwest Monsoon. The southwest monsoon season develops in response to the northward movement of the subtropical ridge in the western Pacific. It begins in April with increasing insolation in the Northern Hemisphere. As the subtropical ridge moves northward and strengthens, changes in the general circulation pattern takes place. The cold, dry, Asiatic high is replaced by the Asiatic low. A developing high replaces the thermal low over Australia. The subtropical jet (STJ) moves north of the Tibetan Plateau and gradually decreases in intensity while the Tibetan high settles aloft over the plateau. The tropical easterly jet (TEJ) sets up south of the Himalayas, and the NETWC begins its northward movement into the South China Sea. All of this activity results in cross-equatorial flow that allows air streams from the Indian Ocean, Australian and South Pacific Ocean highs to penetrate well north of the equator. These southerly winds reach peak intensity and northernmost advance in July and August before their southward retreat begins in September.

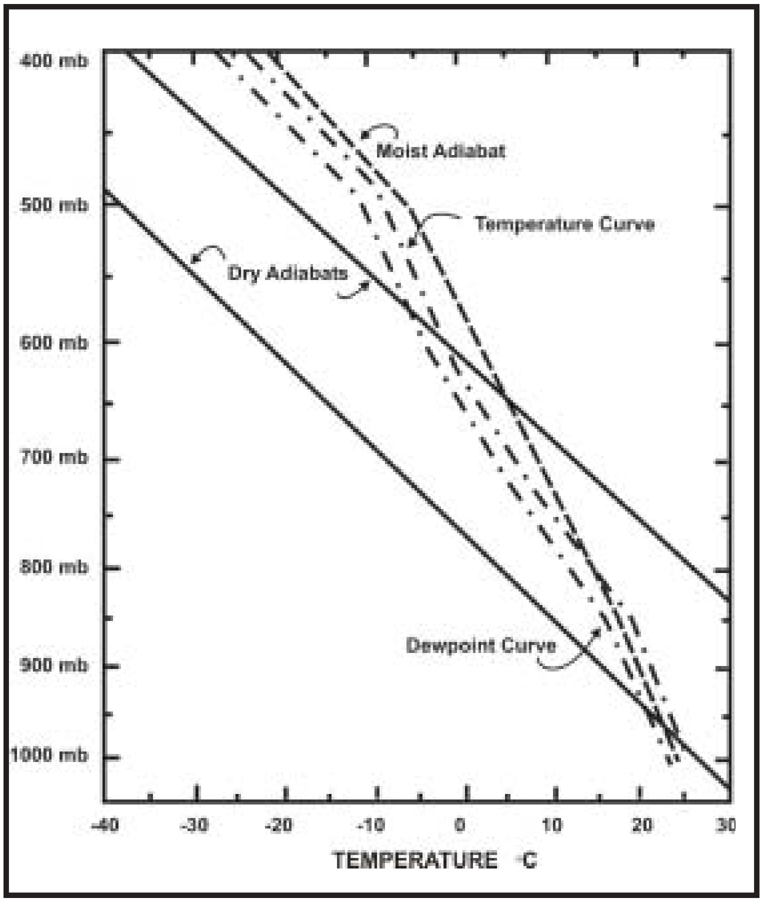

Figure 2-13. Typical Indian Southwesterlies Sounding. The temperature lapse rate parallels the moist adiabat. Note the high moisture content at the upper levels. This property distinguishes the Indian southwesterlies from the North Pacific trades. (From Estoque, 1956).

The primary wind flow of the southwest monsoon is called the Indian southwesterlies. This brings a west to southwesterly flow of maritime equatorial air into the western Pacific region. It consists of the Indian Ocean trades, which deflect eastward upon crossing the equator. The transport of air into the Northern Hemisphere occurs across a line from a point near Eastern Africa to a point just west of Sumatra. This air stream often attains considerable depth (from the earth's surface up to 30,000 feet). This air stream is quite humid. During July and August, the relative humidity is generally more than 80 percent throughout the air stream's vertical extent. Consequently, the temperature lapse rate is moist adiabatic (Figure 2-13). As a result, thunderstorm activity in the Indian southwesterlies is more intense than in the North Pacific trades.

Monsoon Breaks. These occur when an equatorial anticyclone (also called a buffer ridge) forms along the equator and migrates northward (Figure 2-14). When the break is severe, it is evident at 500 mb as a ridge from the North Pacific high. During breaks, maximum convective activity shifts northward into central China. In addition, branches of the NETWC tend to develop on both sides of the equator. During monsoon breaks, low-level westerlies are weak and may even be replaced by easterlies. Precipitation also increases significantly in the equatorial western Pacific basin as disturbances move along the NETWC. The disturbances bring short, but intense rain spells to Borneo, Sumatra and Java. The monsoon break ends when a mid-latitude trough moves southward and shifts the subtropical ridge eastward.

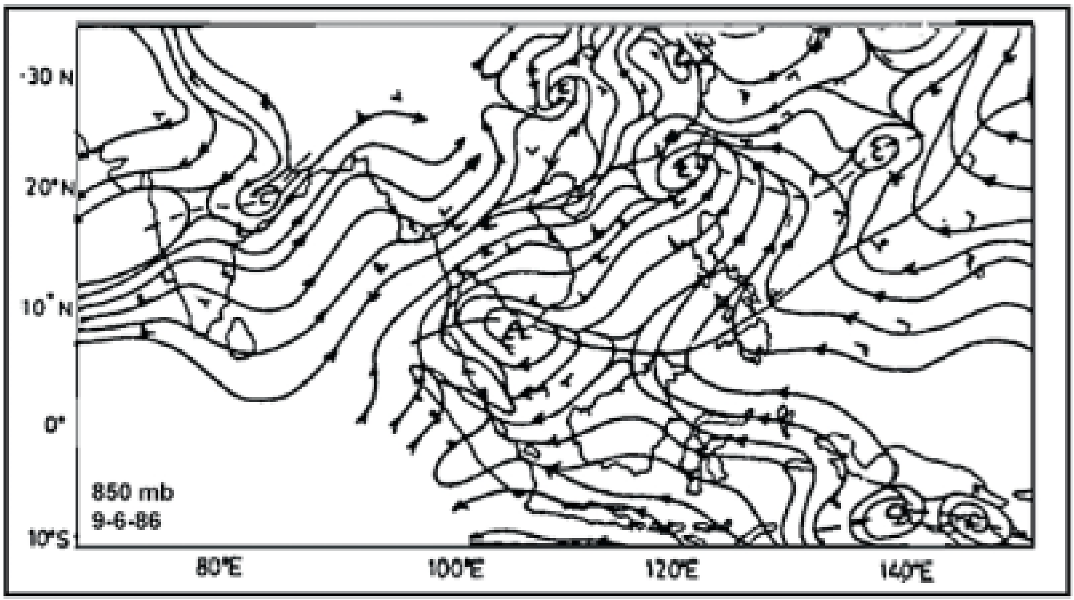

Figure 2-14. Streamline Analysis (850 mb) from 9 June 1986. This analysis shows presence of an equatorial anticyclone over the Gulf of Thailand. This anticyclone migrated northward to cause a "monsoon break" to occur. (From Cheang and Tan, 1988).

Equatorial Westerlies. Outflow from the South Indian Ocean high forms a band of westerlies along the African coast and eastward to 130° East. In Northern Hemisphere summer, outflow from the Australian high strengthens the band around 110° E. The westerly flow extends from surface to 700 mb, but in July, its strongest month, it extends to 500 mb. The equatorial westerlies provide cool, subsiding air between the northern and southern monsoon boundaries. Easterly waves form in this flow.

Southern Oscillation (El Niño, La Niña). This complex, global atmosphere/ocean interaction of periodic changes in atmospheric pressure, sea-surface temperature, and air temperature is characterized by two phases, a warm "El Niño" and a cold "La Niña", with short, intervening transitions. The time to complete one cycle varies between 2 and 10 years and averages around 3 years. Equatorial atmospheric circulation changes in association with these phases are shown in Figure 2-15.

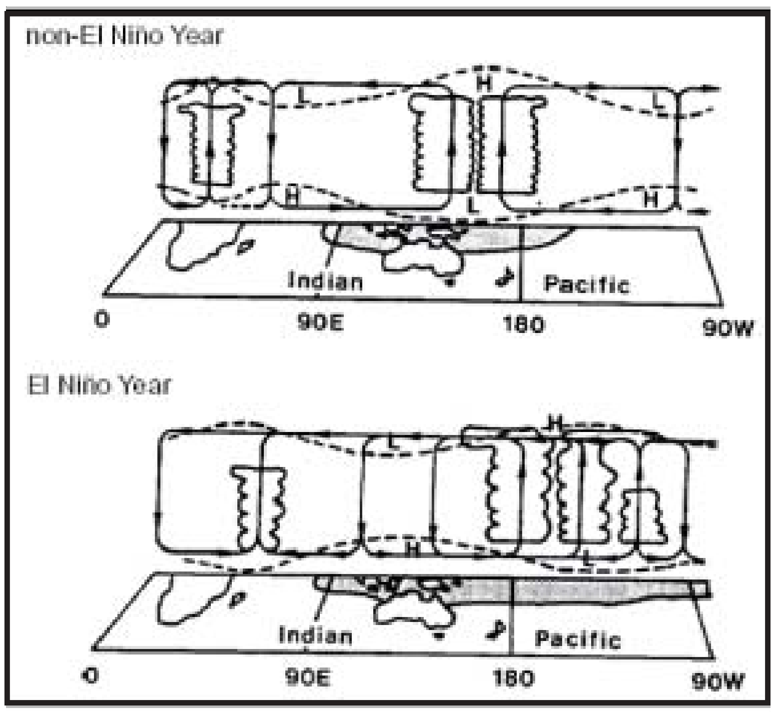

Figure 2-15. Equatorial Circulation Model during Non-El Nino and El Nino Years. Shows eastward shift of circulation pattern in response to sea-surface warming in the Eastern Pacific. Shaded areas indicate sea surface temperatures exceeding 81°F (27°C). (From Cheang and Tan, 1988).

El Niño. The El Niño lasts an average of 18 months. It begins with elevated sea-surface temperatures in the Eastern Pacific, usually in December. These temperature anomalies gradually diminish as they propagate westward, and temperatures in the western Pacific Ocean are 2-5 degrees *below* normal. These lower temperatures are linked to changes in the monsoon over India and the western Pacific Basin. El Niño also appears to be connected to variations in sea-surface temperatures in the Atlantic Ocean. The El Niño begins to appear in the western Pacific during March and April and reaches peak intensity during the southwest monsoon season. It lasts well into the northeast monsoon. During an El Niño year, there are radical changes to the monsoon system. The North Pacific high strengthens and shifts unusually far south during the southwest monsoon. The high covers a larger area and extends farther west. Also, the NETWC shifts closer the equator. In the Southern Hemisphere, the South Pacific high weakens and the SPCZ shifts eastward towards the dateline. During the northeast monsoon, both the NETWC and the SIOT generally disappear, replaced by easterlies. In the upper troposphere, the subtropical westerlies prevail to the equator. Except for the northern Philippines, the western Pacific basin experiences a decline in precipitation during an El Niño (see Figure 2-16). Drought conditions occur in Indonesia and the Caroline Islands. Northeast monsoon cold surges occur less frequently. Except for the region northwest of Australia, there is a significant decrease in tropical cyclone activity, especially between July and November.

La Niña. When a La Niña is underway, conditions in the western Pacific basin are almost opposite of those under an El Niño. Sea-surface temperatures are above normal. The North Pacific high is weak and the South Pacific high is stronger than normal. The SPCZ lies further west than normal, which leads to above normal precipitation for the equatorial regions (Figure 2-17). Tropical cyclone activity is also above normal for the region.

Trade Wind Belts. A belt of tropical easterlies exists between the NETWC and the subtropical high pressure cells (Figure 2-18). The northeast trades in the Northern Hemisphere and the southeast trades in the Southern Hemisphere are two of its components. These wind systems are encountered about 80-90 percent of the time. The two trade wind belts in the western Pacific basin are the *North Pacific trades* and the *South Pacific trades*.

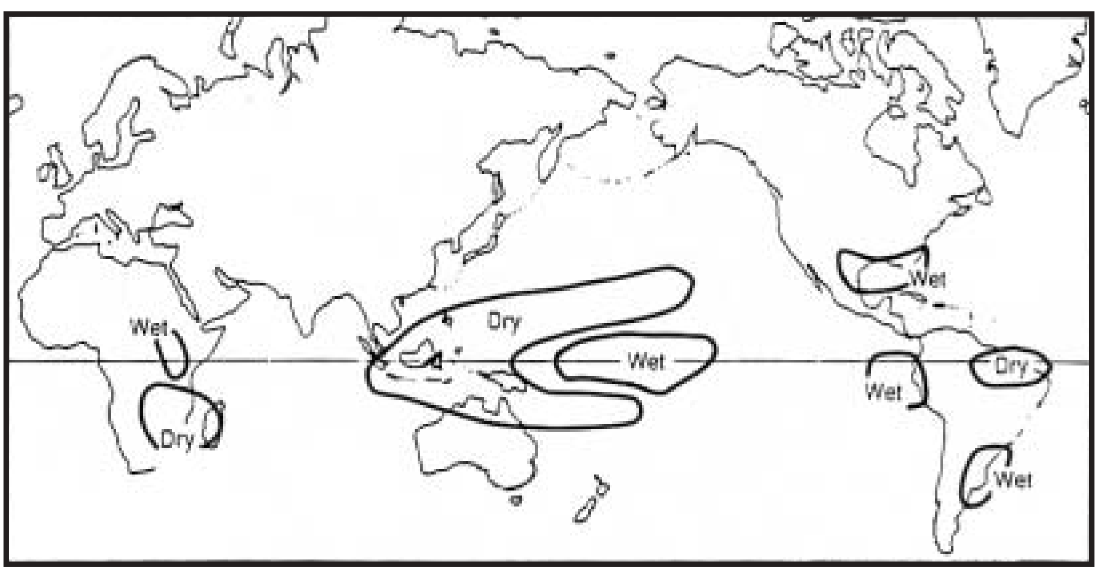

Figure 2-16. Precipitation Anomalies during El Nino Episodes. The graphic depicts wet and dry areas associated with El Nino episodes.

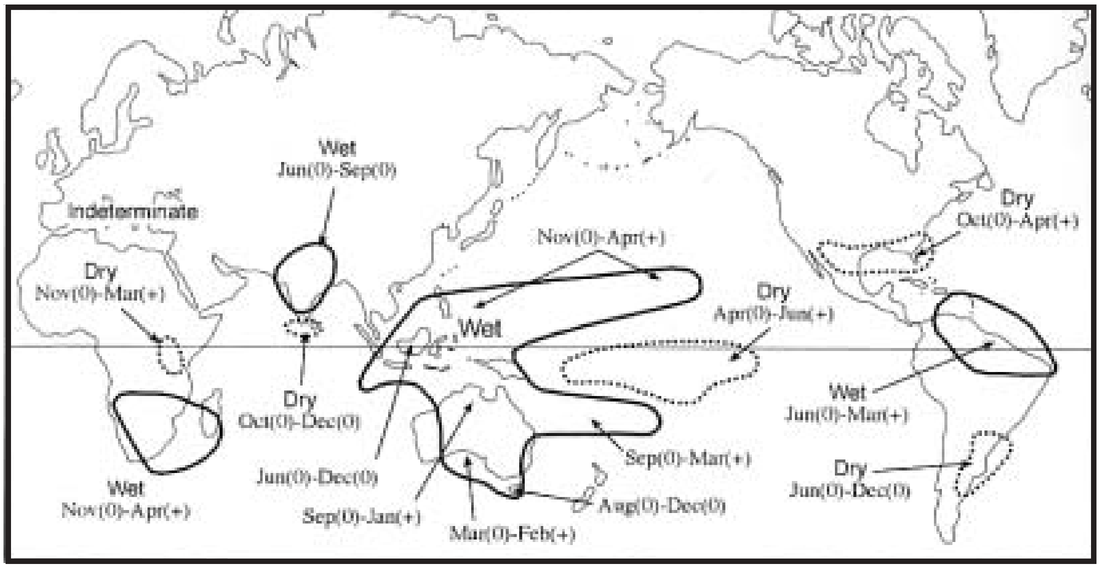

Figure 2-17. Precipitation Anomalies during La Nina Episodes. Solid lines indicate areas where precipitation amounts were above normal. Dashed lines indicate dry areas (areas below normal precipitation).

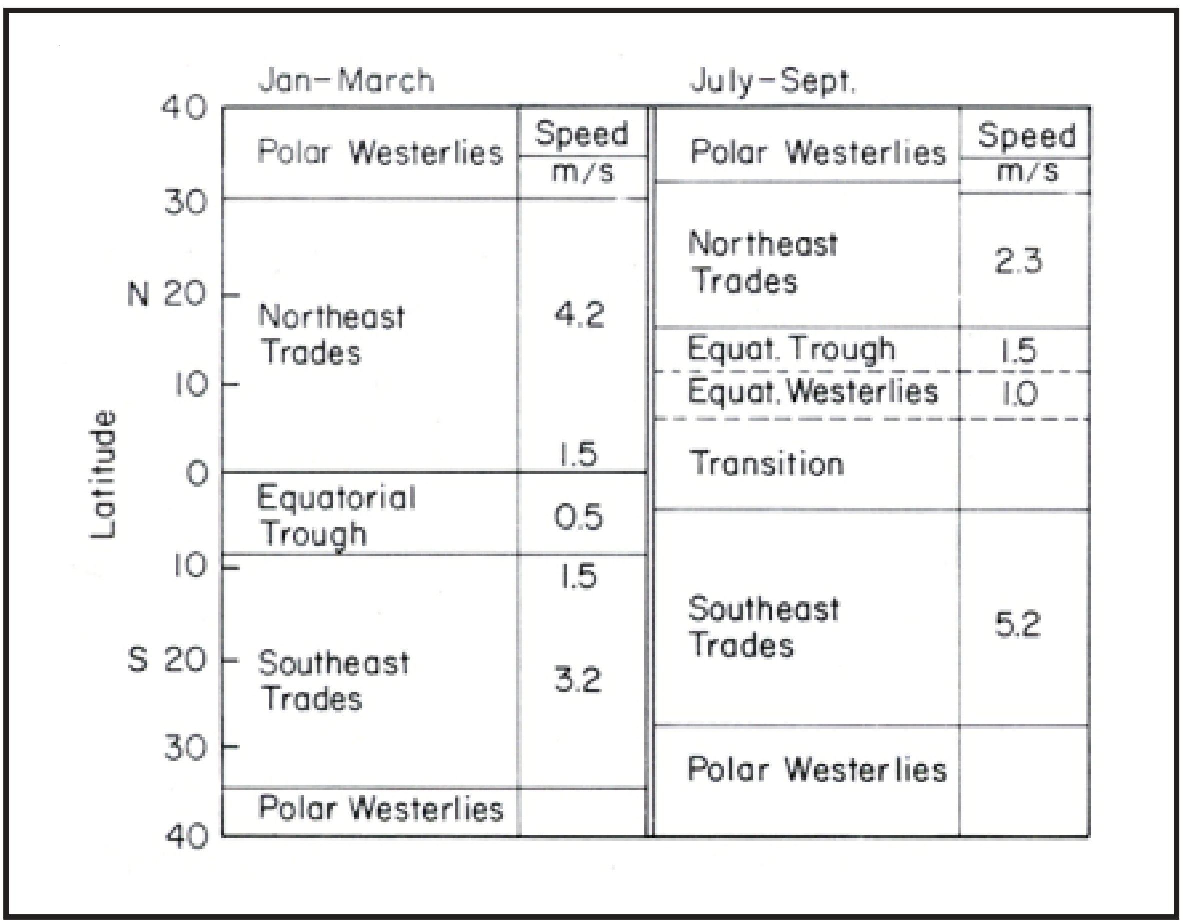

Figure 2-18. Latitudinal Distribution of Surface Winds in Summer and Winter. (From Riehl, 1979).

North Pacific Trades. The North Pacific trades are a very deep wind system that brings maritime tropical air into the region from the east. They extend to the tropopause near the equator and have a near-barotropic vertical wind distribution. The source region for this air stream is the southern portion of the North Pacific high. Here the air stream is characterized by a strong subsidence inversion (known as the *trade wind inversion*) at a height of one to two kilometers. The inversion separates the moist air near the surface from the dry air above. Consequently, convection is limited to the airmass below the inversion level. As the air stream moves into the western Pacific, the characteristic temperature inversion is weakened and becomes only a decrease in the lapse rate. The associated decrease in the moisture, generally below 25 percent relative humidity above the trade wind inversion, remains well defined, however, if the air stream undergoes a dynamic destabilization process, such as surface convergence, the stable stratification aloft is destroyed, and the inversion is wiped out. Convective activity then becomes more intense as it transports moisture upward to great heights. This type of modification occurs frequently during typhoon season in the western North Pacific, especially near the NETWC where the air stream becomes quite moist in the upper levels. Figure 2-19 show a typical sounding of the North Pacific trades air stream near its source region and after it has been subjected to the destabilization process.

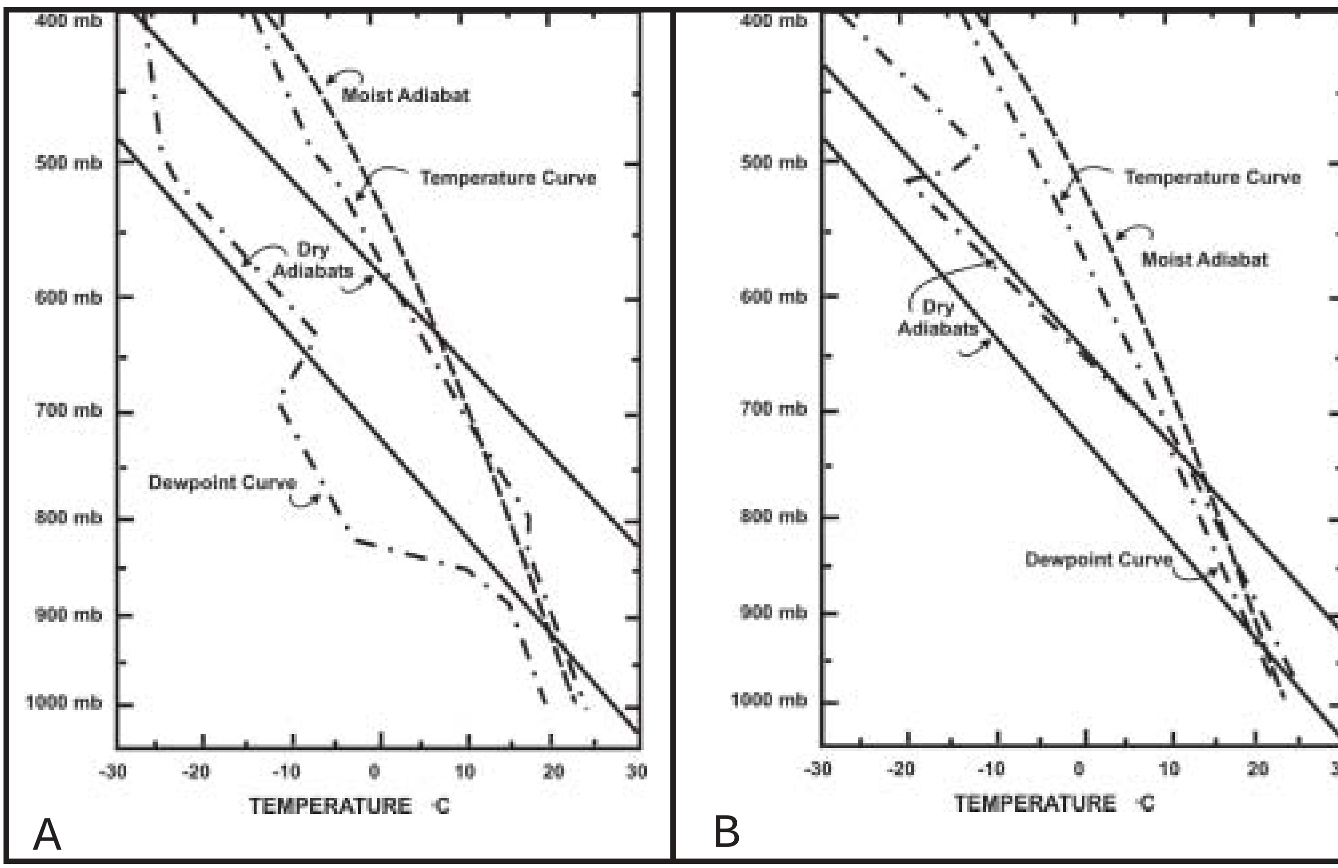

Figure 2-19. North Pacific Trade Wind Vertical Profiles. These soundings are typical of the structure of the North Pacific tradewind flow near the source region (A), and when the flow has undergone modification (B). Near its source region, a strong subsidence inversion exists at a height of 3,200 - 6,400 feet (1-2 km) MSL resulting in a moist layer near the sea surface and a dry layer above the inversion level. If the wind flow encounters a dynamic destabilizing process such as surface convergence, the inversion is destroyed and upper levels become more moist. (From Estoque 1956).

Localized convection, which breaks the tradewind inversion, does not weaken the tradewinds because the break is accompanied by strengthening of the inversion all around it. In fact, greater amounts of precipitation are associated with stronger tradewinds and with lower tradewind inversions. The convective clouds break through the lower inversion earlier in the developmental phase and can grow more rapidly from that point than if they encountered an inversion higher. Another factor is terrain-induced convergence tends to be more concentrated under a lower inversion and triggers more activity than under a higher one.

The weather with the North Pacific trades depends upon the extent of the destabilization process. When the air stream is near its source, the North Pacific high, the air is characterized by the trade wind inversion. As long as this inversion prevails, only limited convective cloud may form; fair-weather cumulus prevails. Towering cumulus and showers are possible in areas of topographic convergence. A distinguishing characteristic of the daytime convective clouds in the North Pacific trades is they tend to dissipate in the evening over the land areas. During typhoon season, the North Pacific high is weak. Consequently, general convergence takes place within the air stream and the trade wind inversion is destroyed. This results in the intensification of the convective activity in the western Pacific with cumulus congestus and even cumulonimbus clouds in the afternoons.

South Pacific Trades. The South Pacific trades originate in the South Pacific high. The air current moves towards the west-northwest across the East Indies or over northern Australia. It veers towards the north and northeast after it crosses the equator. Soundings indicate its thermodynamic properties are similar to that of the North Pacific trades (Figure 2-20). This air stream is relatively dry at the upper levels and frequently shows traces of a trade wind inversion. Although there is a significant moisture increase as it moves over the East Indies, the additional moisture is not enough to make it comparable to the Indian southwesterlies. The South Pacific trades are considered a transition type between the maritime tropical and maritime equatorial air masses.

Jet Streams. The primary jet streams affecting this region are the subtropical jet (STJ), the tropical easterly jet (TEJ), and the tropical low-level jets. These are described below.

Subtropical Jet (STJ). The western Pacific basin is close to the subtropical jet streams of both hemispheres. The STJ is the branch of the mid-latitude westerlies situated closest to the equator. The position of the STJ is dependent upon the season. It is closest to the western Pacific basin during the Northern Hemispheric

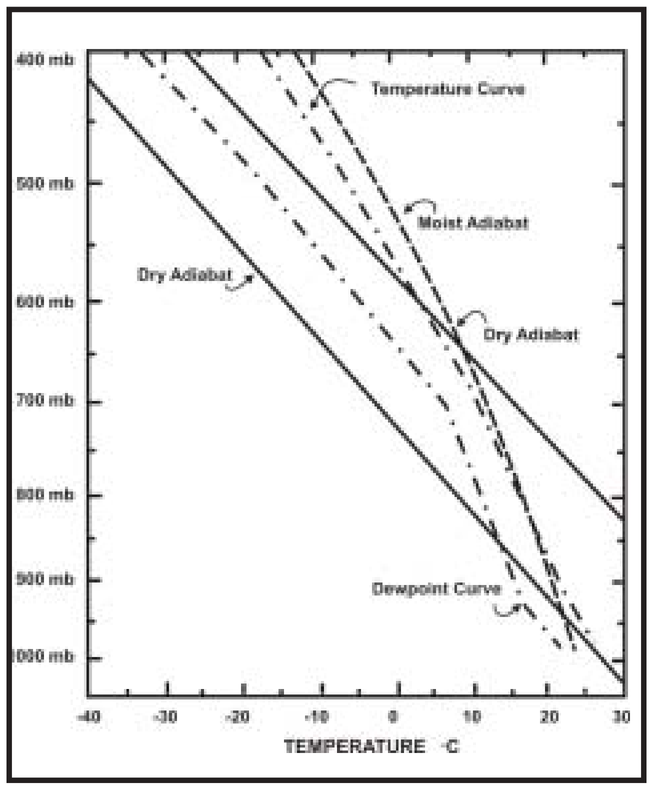

Figure 2-20. Typical Sounding in the South Pacific Trade Stream over the Western Pacific. The moisture content in the upper levels is greater than that found in the upper levels of the North Pacific Trades, but considerably less than is found in the upper levels of the Indian Southwesterlies. (From Estoque 1956).

winter. Figure 2-21 shows the STJ's mean position during January, April, July and October. The characteristics of the STJ are similar in both hemispheres. The mean heights are near 12 km; the mean speeds are 65 knots in winter and 45 knots in summer. The STJ provides upper-level steering, shear and outflow. Rainfall is concentrated along the jet axes. Occasionally, the STJ pushes to within 15 degrees latitude of the equator. In the Northern Hemisphere, the strength of the jet is a good indicator of the strength and characteristics of the North Pacific high. This confluence zone, as seen in Figure 2-22, occasionally enhances cyclogenesis in the South China Sea.

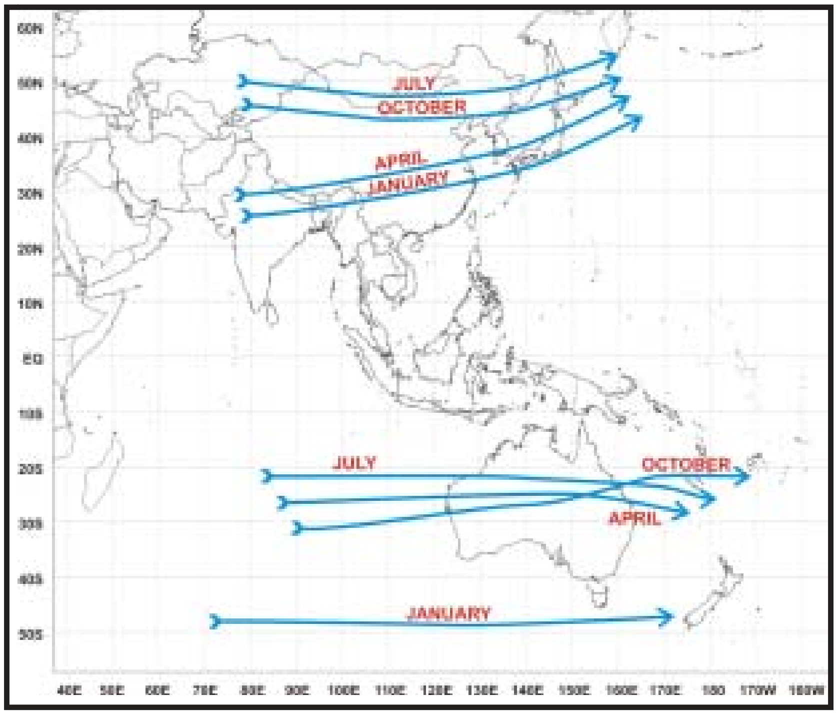

Figure 2-21. January, April, July and October Mean Positions of the Subtropical Jet. (From U.S.. Navy, 1989).

Tropical Easterly Jet (TEJ). This southwest monsoon jet in the upper-level easterlies develops near 200 mb as outflow from the southern periphery of the Tibetan anticyclone. Its entrance region usually lies over the South China Sea, but has been seen as far east as Guam (about 140° East). This jet is strengthened over Southeast Asia by the strong temperature contrast between the warm land and the cooler equatorial water. The TEJ's mean position is near 15° N, 4-5 degrees south of the surface NETWC. It oscillates between

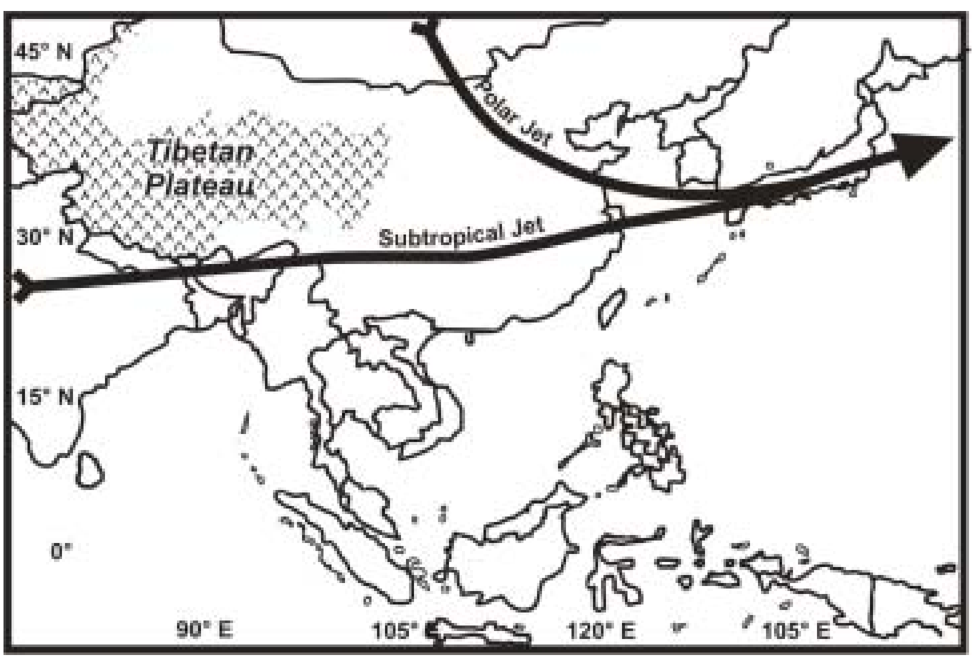

Figure 2-22. Confluence Zone of the Subtropical and Polar Jets. (From Yoshino and Urushibo, 1981).

5° and 20° N (Figure 2-23). The strongest winds are found between 73° and 80° E where speeds reach 90 knots. The mean speed is 60 knots. The jet follows the highest sea-surface temperatures. Since a relatively cool water area often develops in the South China Sea north of Borneo, the TEJ sometimes splits into two axes near 5° N and 20° N (Figure 2-24). Although the northern branch is stronger, it weakens when the South China Sea low-level jet weakens. The TEJ's position and intensity significantly impact the southwest monsoon rains and low-level trade winds. It also provides an outflow mechanism for NETWC convection. Fluctuations in the TEJ's strength are connected to "pulses" in the monsoon flow. Another band of upper-level easterlies is present year-round over the region, but the winds are too weak to represent a true jet. In February, the center of these easterlies reaches 10° S, with speeds of about 35 knots. During the transition seasons, the center is near the equator; speeds average 10 to 20 knots. Even without jet-stream strength, it carries pronounced wave disturbances.

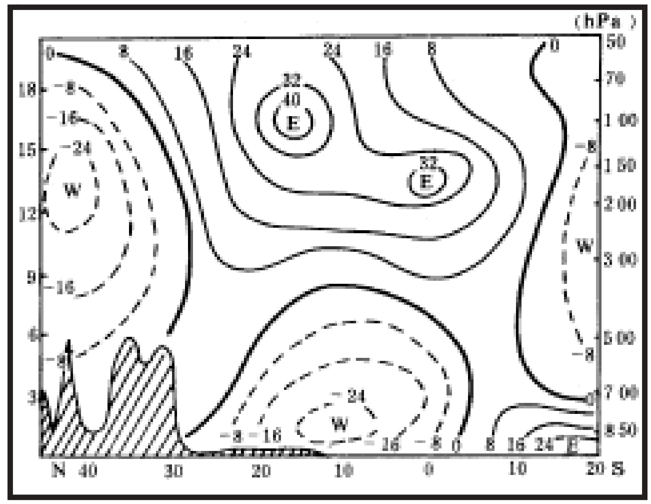

Figure 2-24. Cross-Section of the Mean Zonal Wind Component along 80E in July. Solid (dashed) lines denotes isotach of easterly wind (westerly wind). Units: m/s. (From Yihui, 1994).

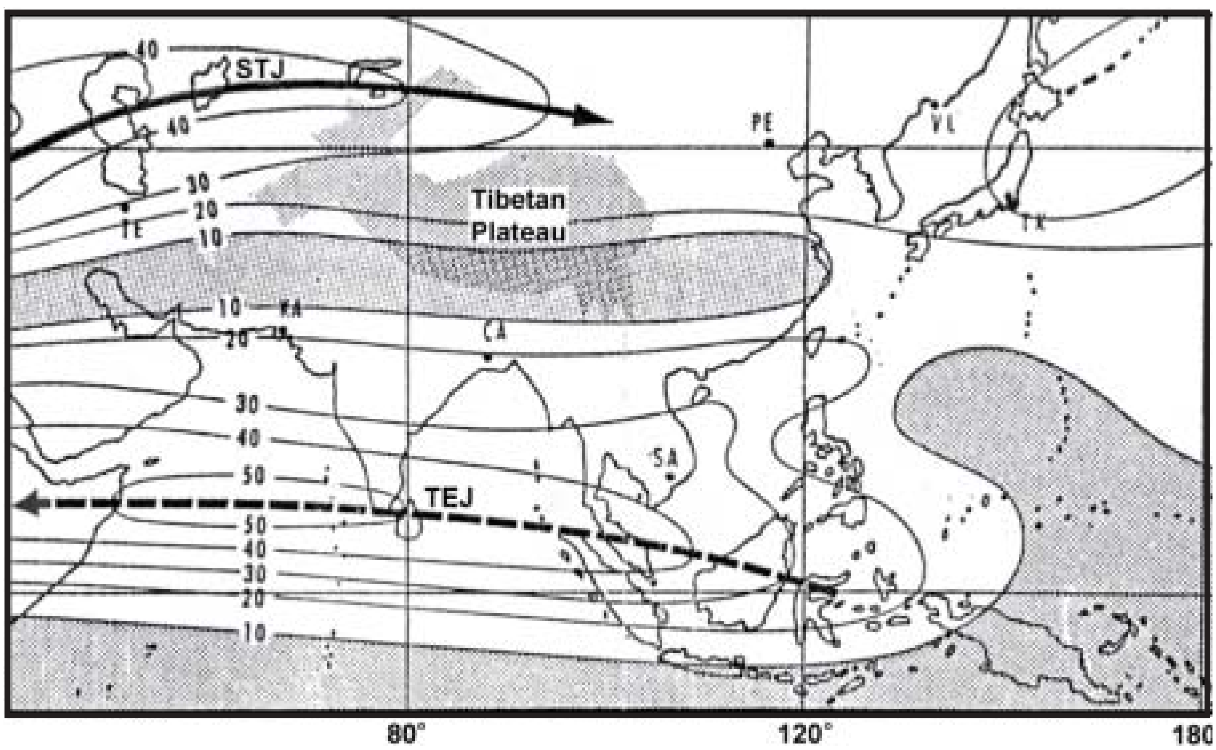

Figure 2-23. Mean July Position of the Tropical Easterly Jet. Wind speed in knots. (From Marcal, 1968).

Tropical Low-Level Jets. Only one low-level jet significantly affects the western Pacific basin. It is a north-flowing, low-level jet that forms between May and October. This jet develops over the warm seas of the equatorial South China Sea during the southwest monsoon. It flows northeast along the east coast of Southeast Asia to about 20° North. Other smaller, short-lived, low-level jets have been identified in the western Pacific basin. They are usually found in areas where mesoscale convective complexes frequently develop.

Gradient-Level Wind Flow Patterns/Features. Analysis of the gradient-level winds is used to identify surface features. Over most of the tropics, the gradient level is about 3,000 feet. For surface locations below 1,000 feet (300 meters) elevation, the 3,000-foot resultant winds are used when available. At stations above 1,000 feet (300 meters), the 5,000-foot resultant winds are used. Over the oceans, resultant winds from ship reports were utilized. Figure 2-25a-d depicts the resultant gradient-level winds for January, April, July and October. Some of the features affecting the western Pacific basin are discussed below.

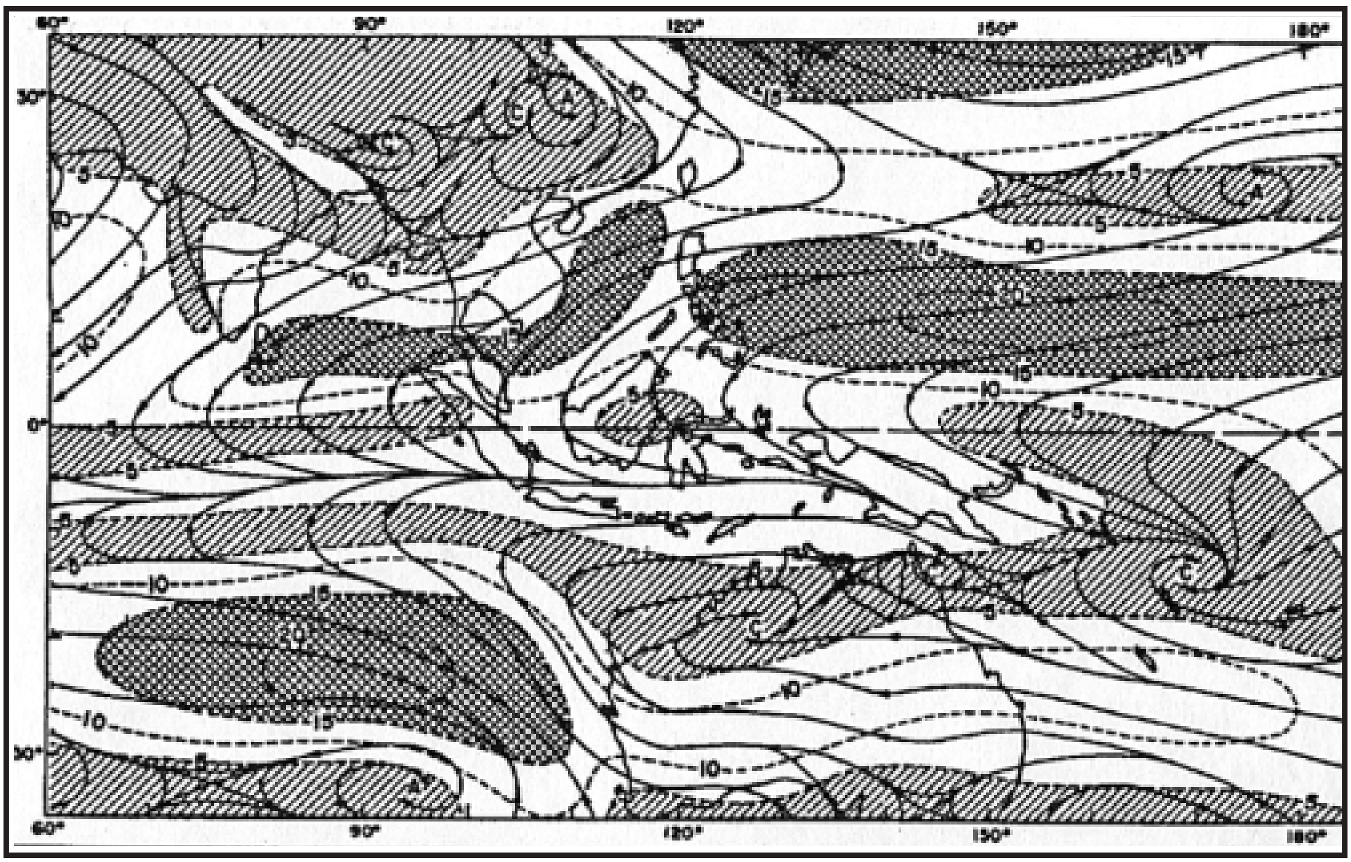

Figure 2-25a. Resultant Gradient-Level Winds (Knots) for January. The full solid lines depict streamlines (arrowheads indicate direction), while the dashed lines depict the resultant isotachs drawn for 5-knot intervals. (From Ramage, 1995).

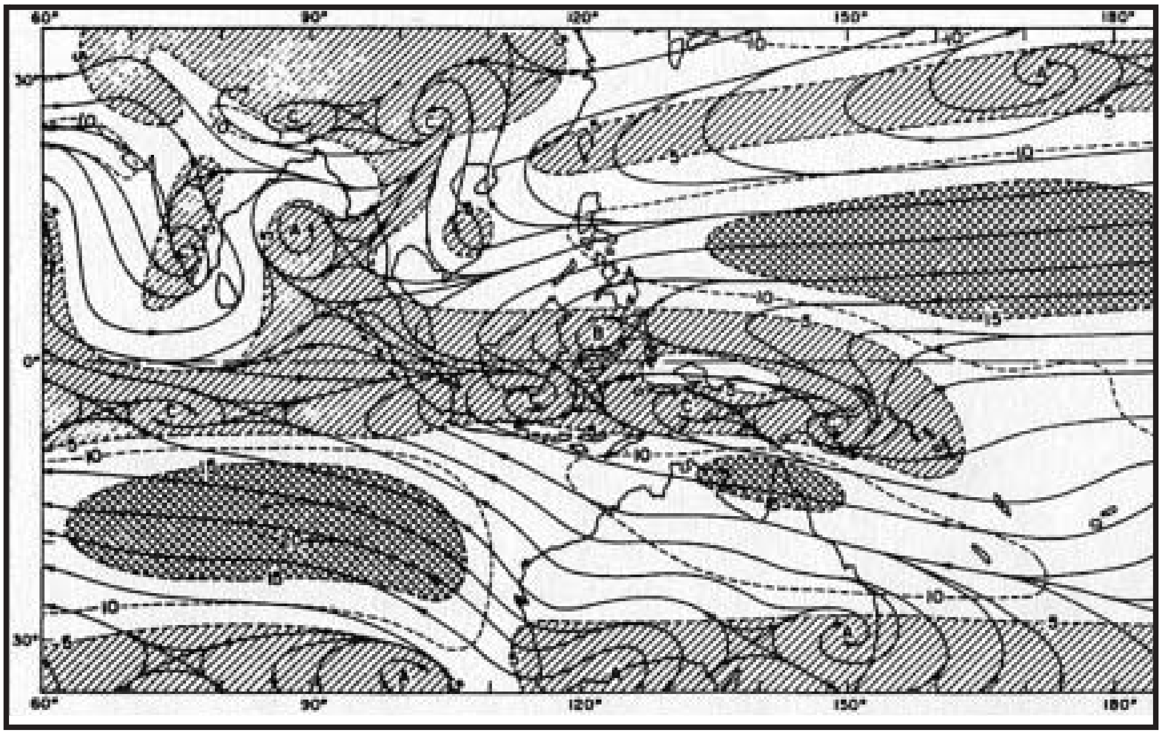

Figure 2-25b. Resultant Gradient-Level Winds (Knots) for April. The full solid lines depict streamlines (arrowheads indicate direction), while the dashed lines depict the resultant isotachs drawn for 5-knot intervals. (From Ramage, 1995).

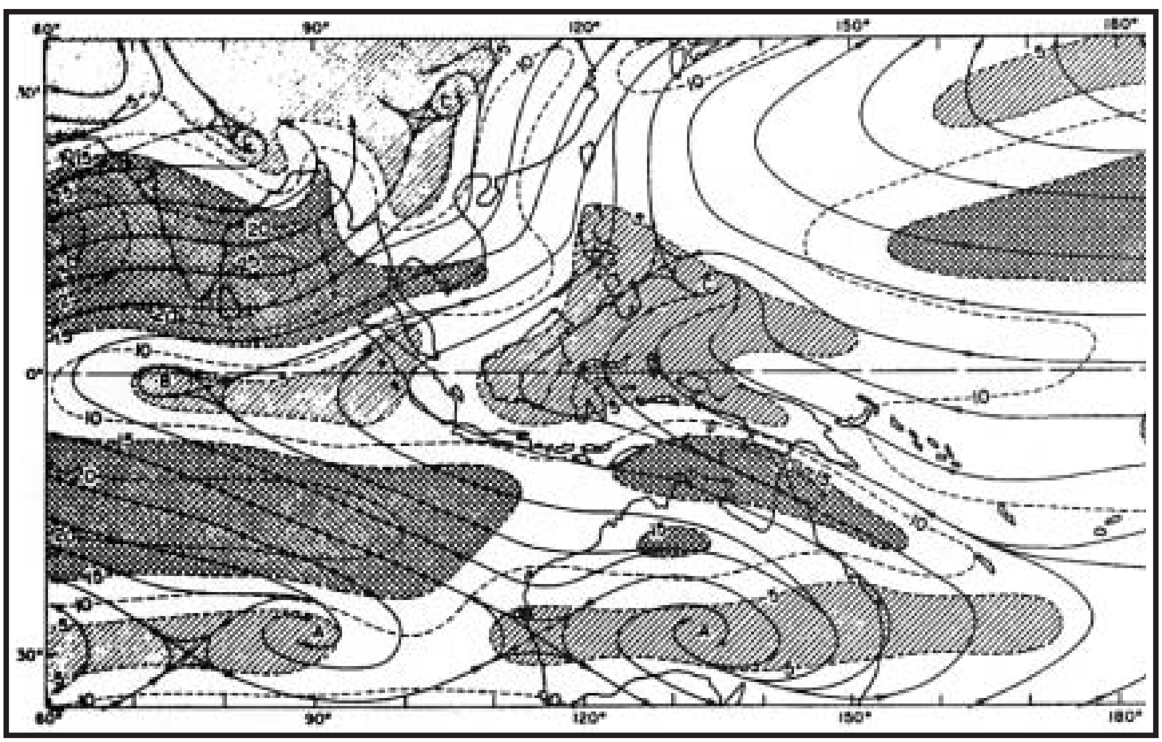

Figure 2-25c. Resultant Gradient-Level Winds (Knots) for July. The full solid lines depict streamlines (arrowheads indicate direction), while the dashed lines depict the resultant isotachs drawn for 5-knot intervals. (From Ramage, 1995).

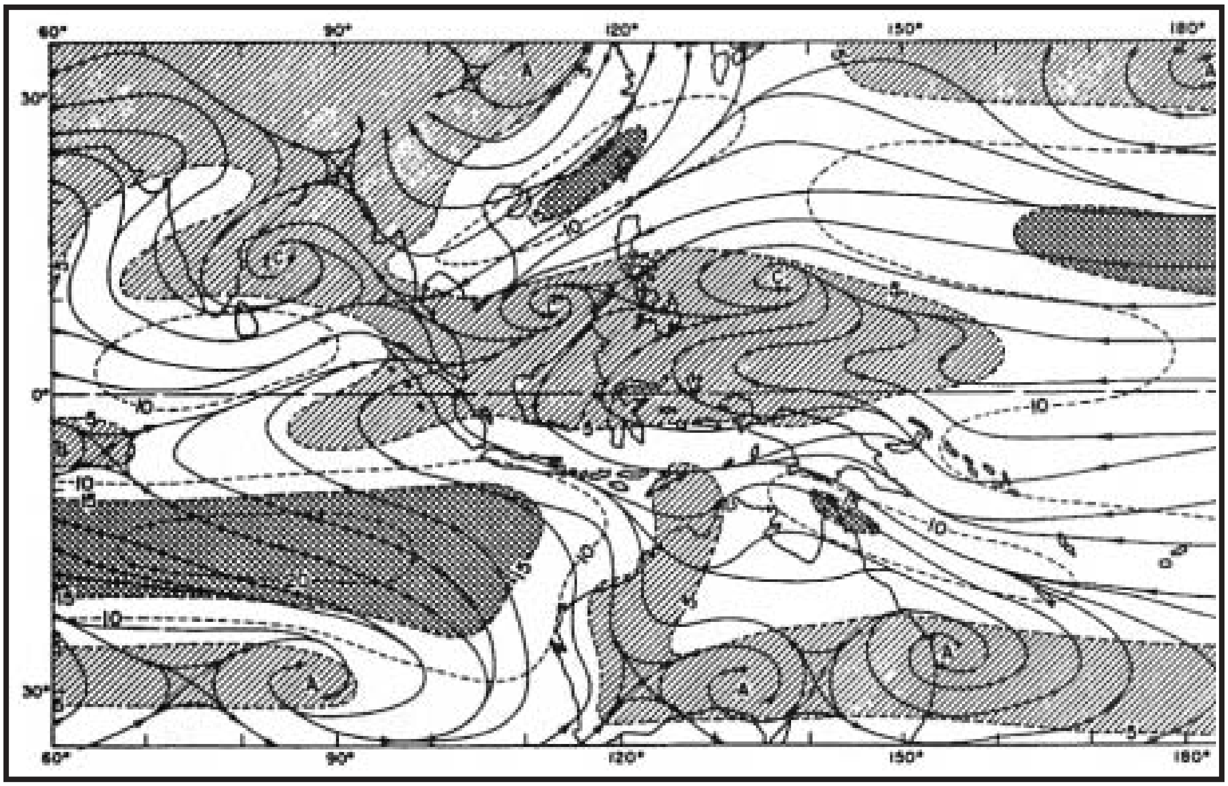

Figure 2-25d. Resultant Gradient-Level Winds (Knots) for October. The full solid lines depict streamlines (arrowheads indicate direction), while the dashed lines depict the resultant isotachs drawn for 5-knot intervals. (From Ramage, 1995).

During January, anticyclones dominate the Asian continents, and heat lows dominate Australia. Outflow from the northeast monsoon and the North Pacific high dominate the region. The wind flow turns towards the southeast as it crosses to south of the equator. It converges with the wind flow from the South Pacific high to form the NETWC south of the equator to the west of Sumatra. The wind flow from the North Pacific high also converges into the NETWC that has set up over Australia. By April, the NETWC begins its northward trek, and the Asiatic low begins to replace the Asiatic high. The northeasterly wind flow that dominated the South China Sea diminishes, which leaves the easterlies from the North and South Pacific high to dominate the region. The Australian thermal high replaces the heat low there. July's pattern depicts the southwest monsoon in full force. A southerly wind flow dominates most of the western Pacific basin. A circulation center to the east of the Philippines reflects the concentration of tropical cyclone tracks in the region. The northeast monsoon begins to develop in October. A trough of low pressure has set up from the Philippine Sea into the South China Sea. This trough is a prime location for the development of tropical cyclones.

Mid- and Upper-Level Wind Flow Patterns/ Features. Figures 2-26a-d show January, April, July, and October streamline flow at 850, 700, 500, and 200 mb. Some of the primary features are described below.

In January, 850-mb anticyclones are prominent along the southern Chinese coast. Southerly flow southwest of these highs pulls warm air into the northern South China Sea. The resultant strong baroclinic zone in southern China initiates strong cold surges typical of the northeast monsoon. A high pressure ridge is over the northern portion of the western Pacific basin at 700 and 500 mb, while the subtropical ridge is at its southernmost position. The trades dominate the region in the lower levels. The transition to the southwest

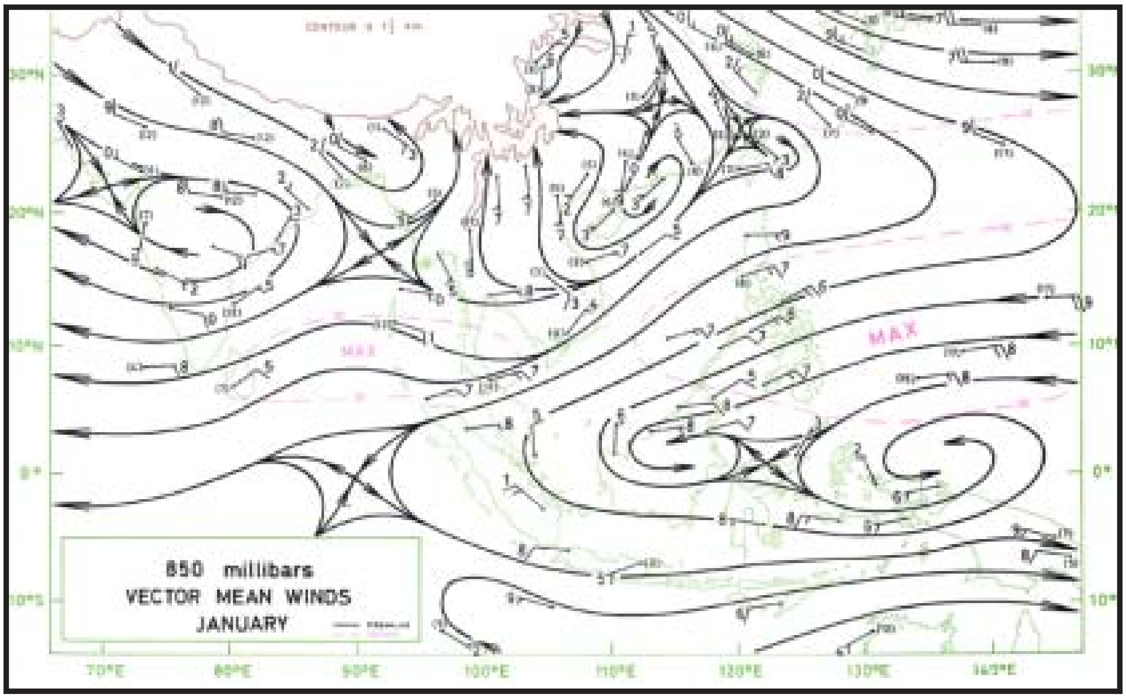

Figure 2-26a-1. Streamline Analysis at 850 mb for January. The full solid lines depict streamlines (arrowheads indicate direction).

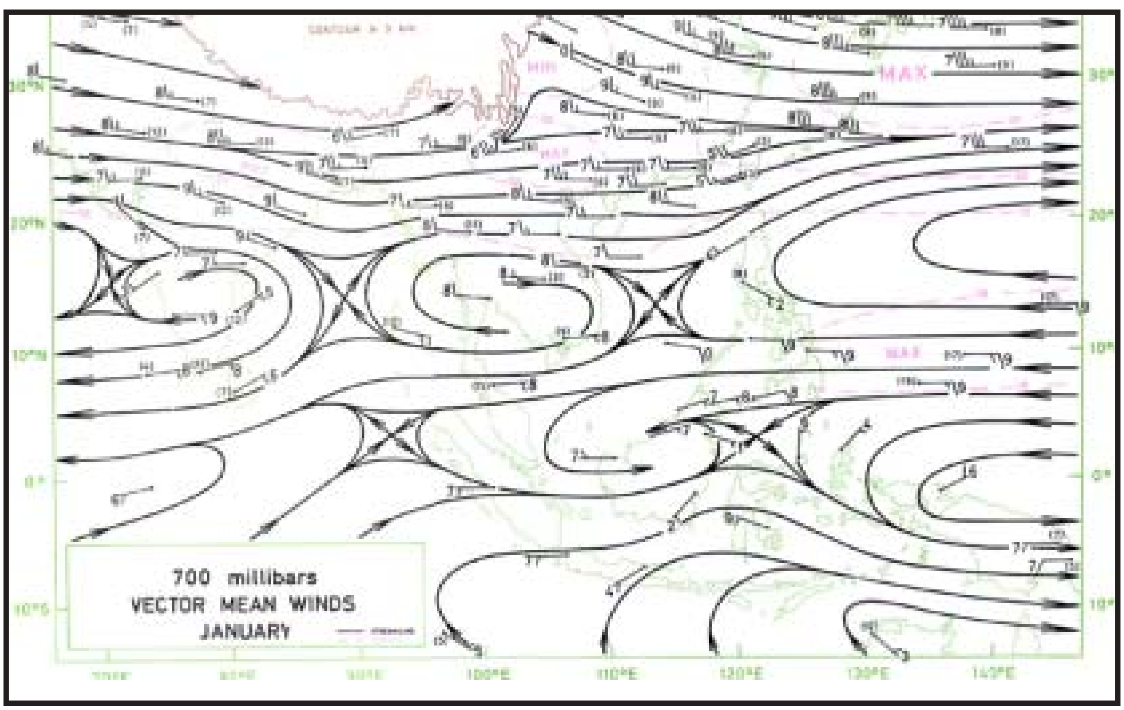

Figure 2-26a-2. Streamline Analysis at 700 mb for January. The full solid lines depict streamlines (arrowheads indicate direction).

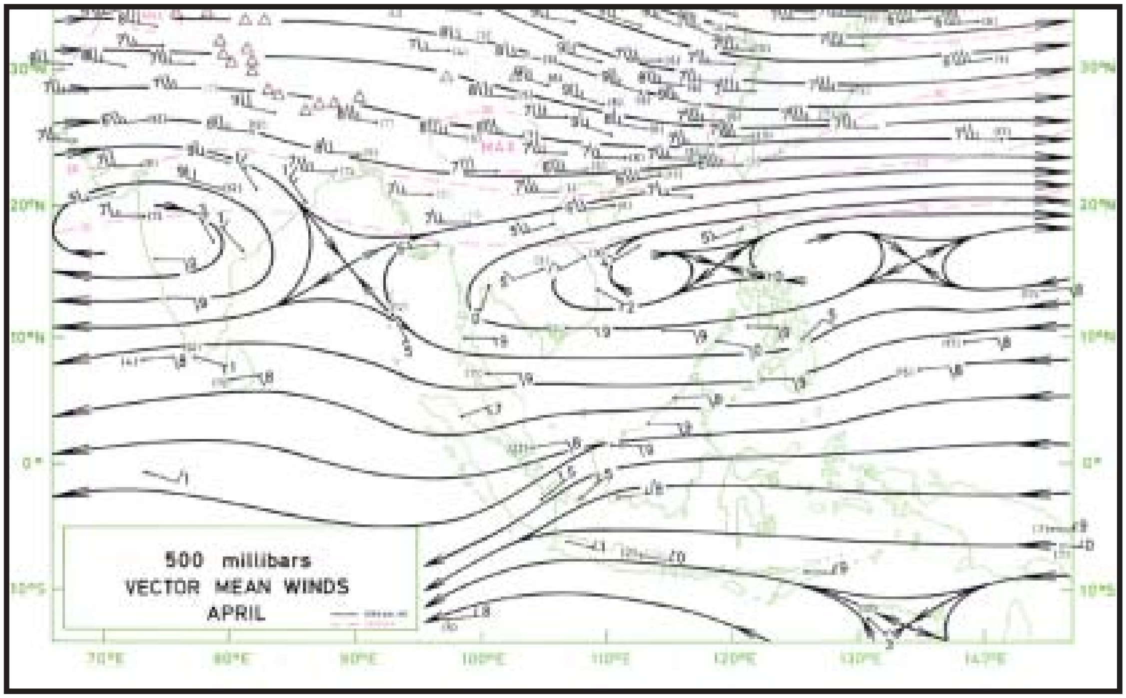

Figure 2-26a-3. Streamline Analysis at 500 mb for January. The full solid lines depict streamlines (arrowheads indicate direction).

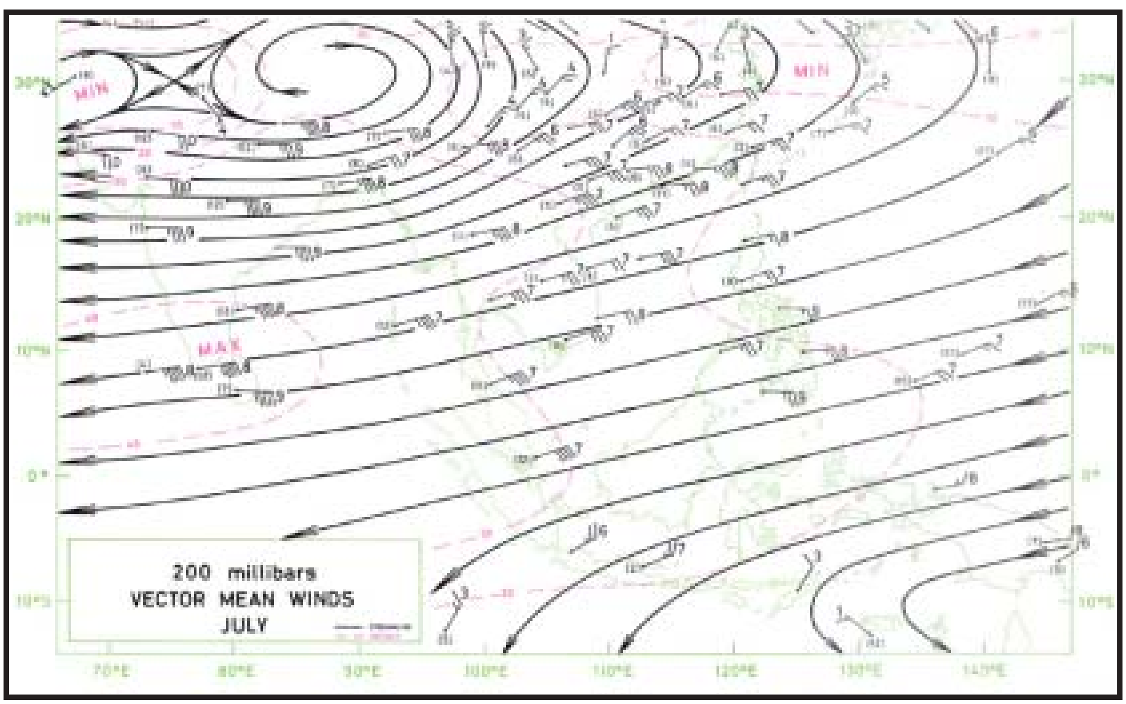

Figure 2-26a-4. Streamline Analysis at 200 mb for January. The full solid lines depict streamlines (arrowheads indicate direction).

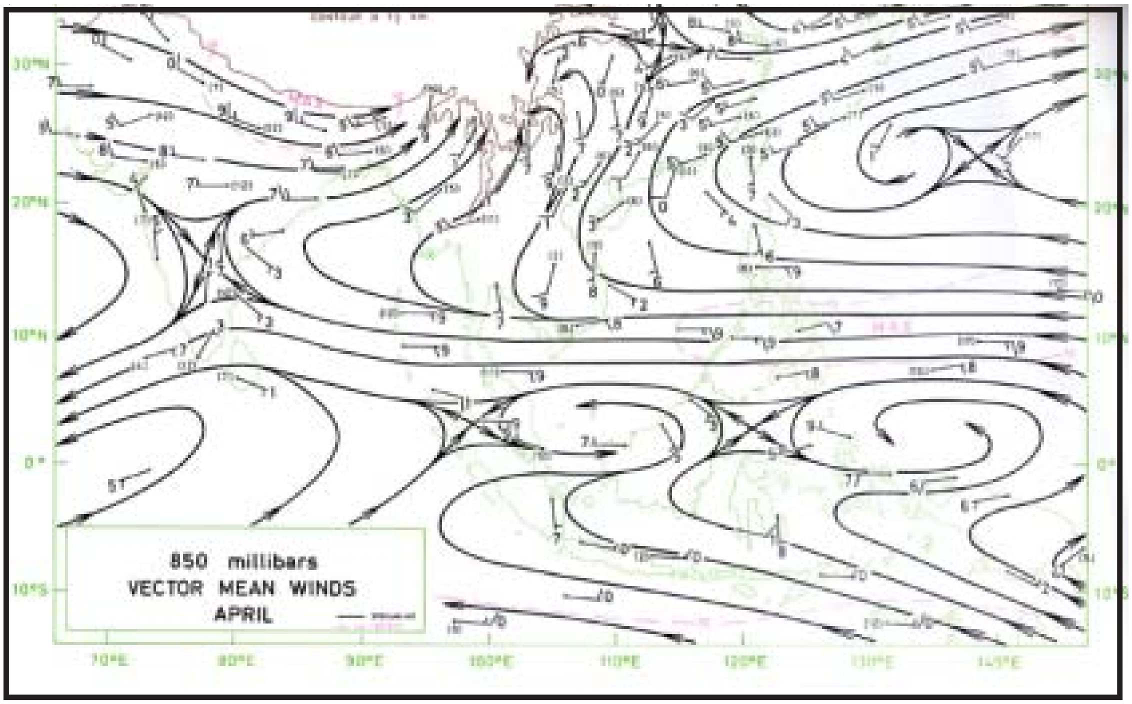

Figure 2-26b-1. Streamline Analysis at 850 mb for April. The full solid lines depict streamlines (arrowheads indicate direction).

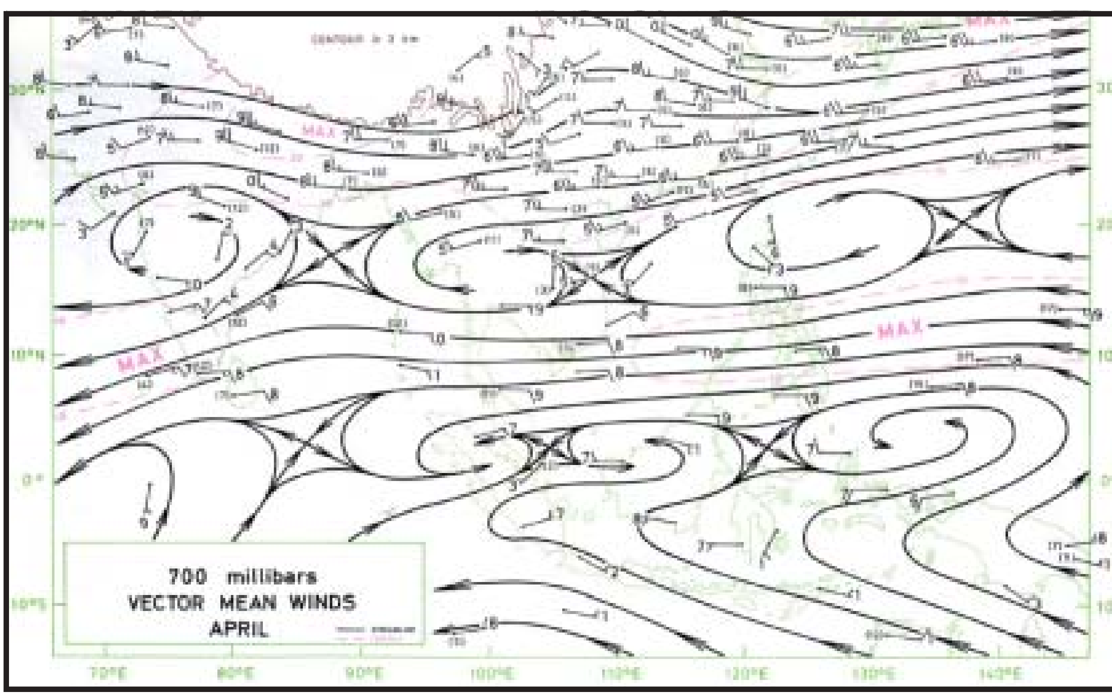

Figure 2-26b-2. Streamline Analysis at 700 mb for April. The full solid lines depict streamlines (arrowheads indicate direction).

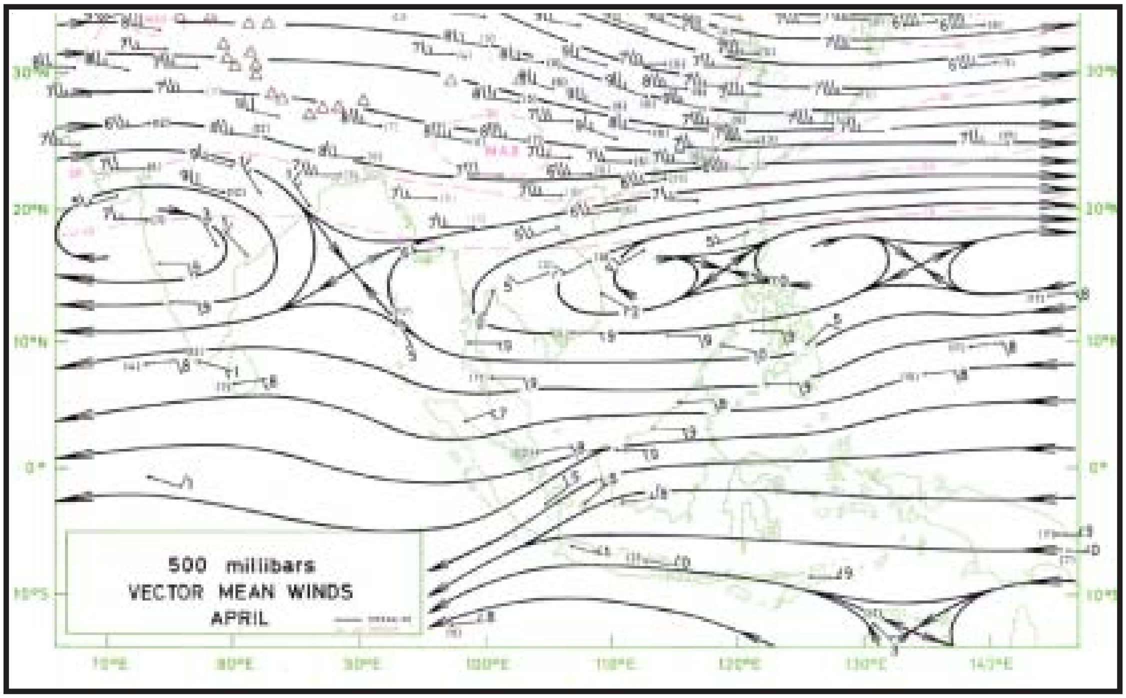

Figure 2-26b-3. Streamline Analysis at 500 mb for April. The full solid lines depict streamlines (arrowheads indicate direction).

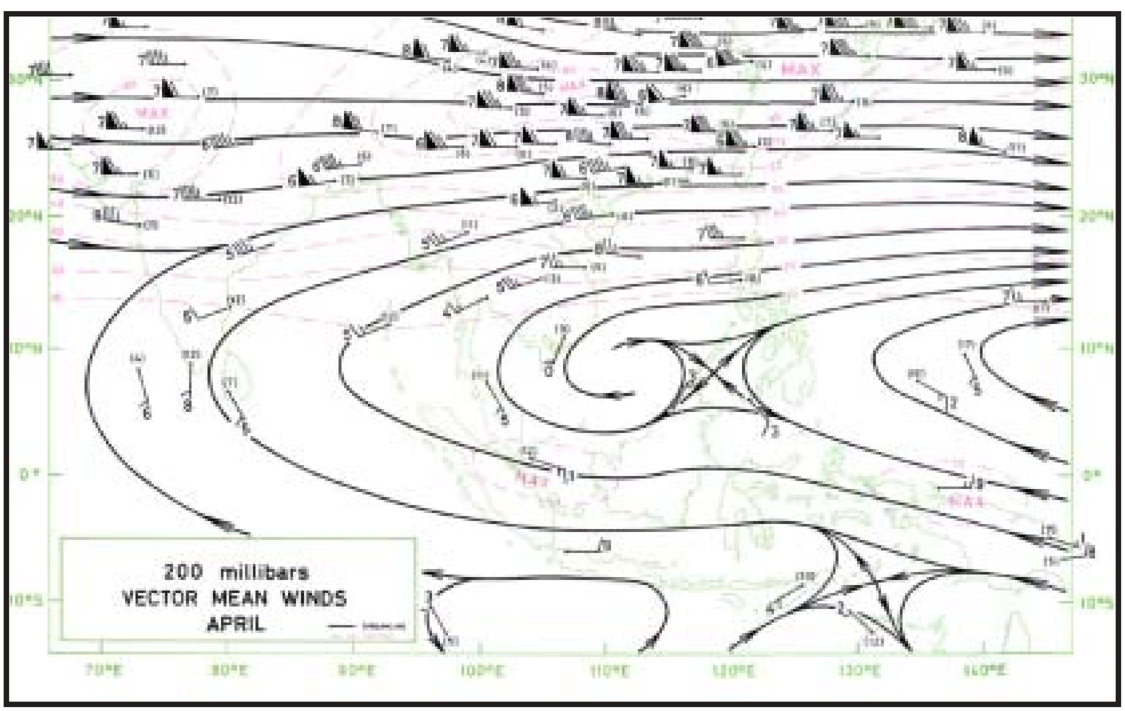

Figure 2-26b-4. Streamline Analysis at 200 mb for April. The full solid lines depict streamlines (arrowheads indicate direction).

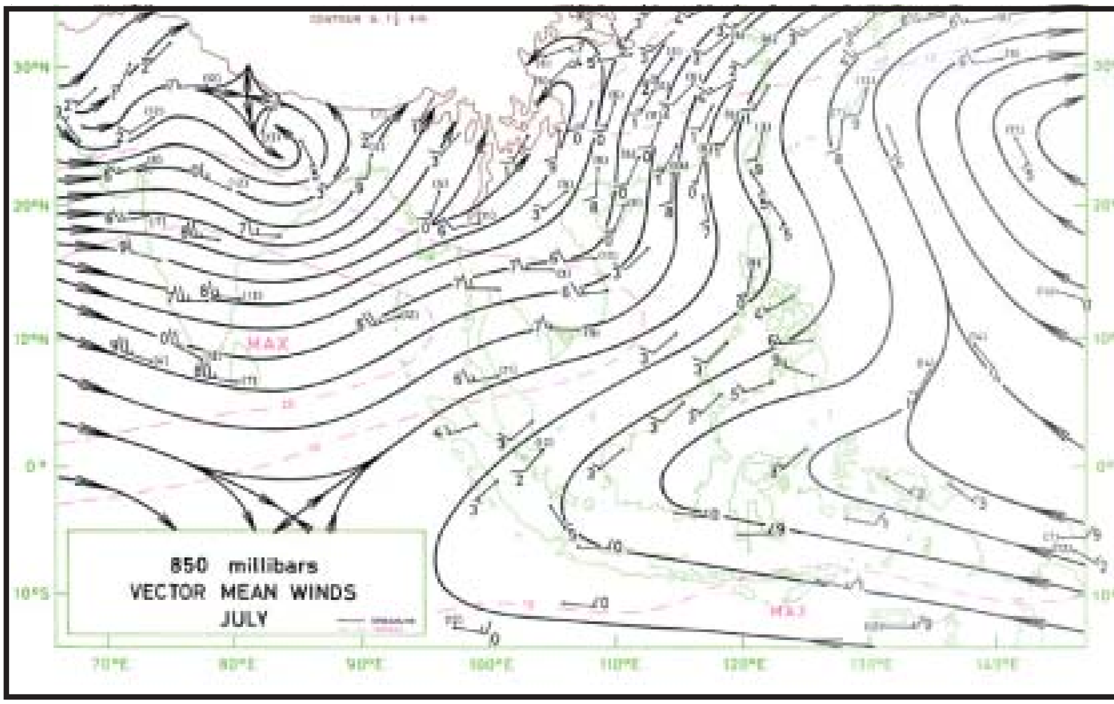

Figure 2-26c-1. Streamline Analysis at 850 mb for July. The full solid lines depict streamlines (arrowheads indicate direction).

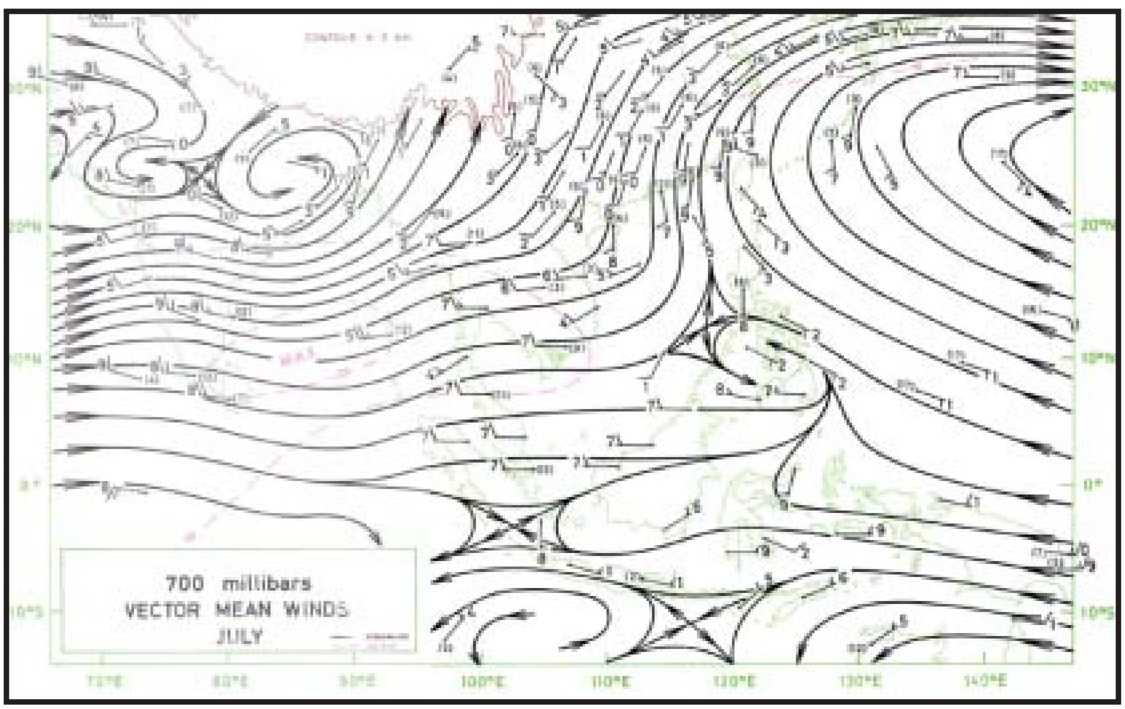

Figure 2-26c-2. Streamline Analysis at 700 mb for July. The full solid lines depict streamlines (arrowheads indicate direction).

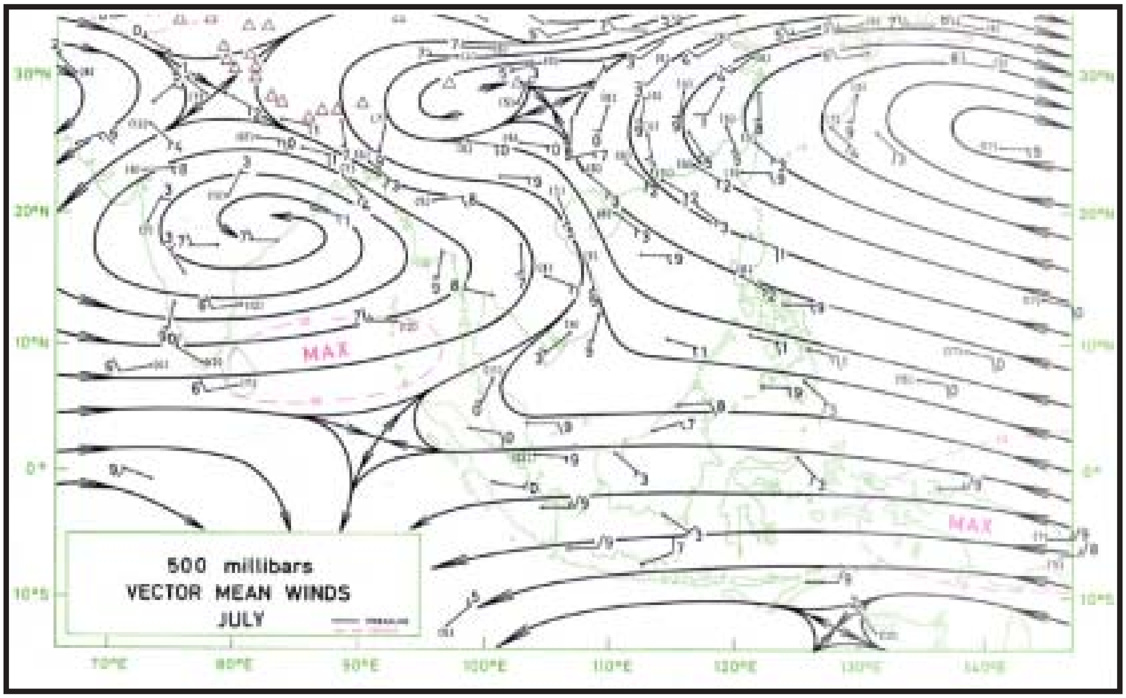

Figure 2-26c-3. Streamline Analysis at 500 mb for July. The full solid lines depict streamlines (arrowheads indicate direction).

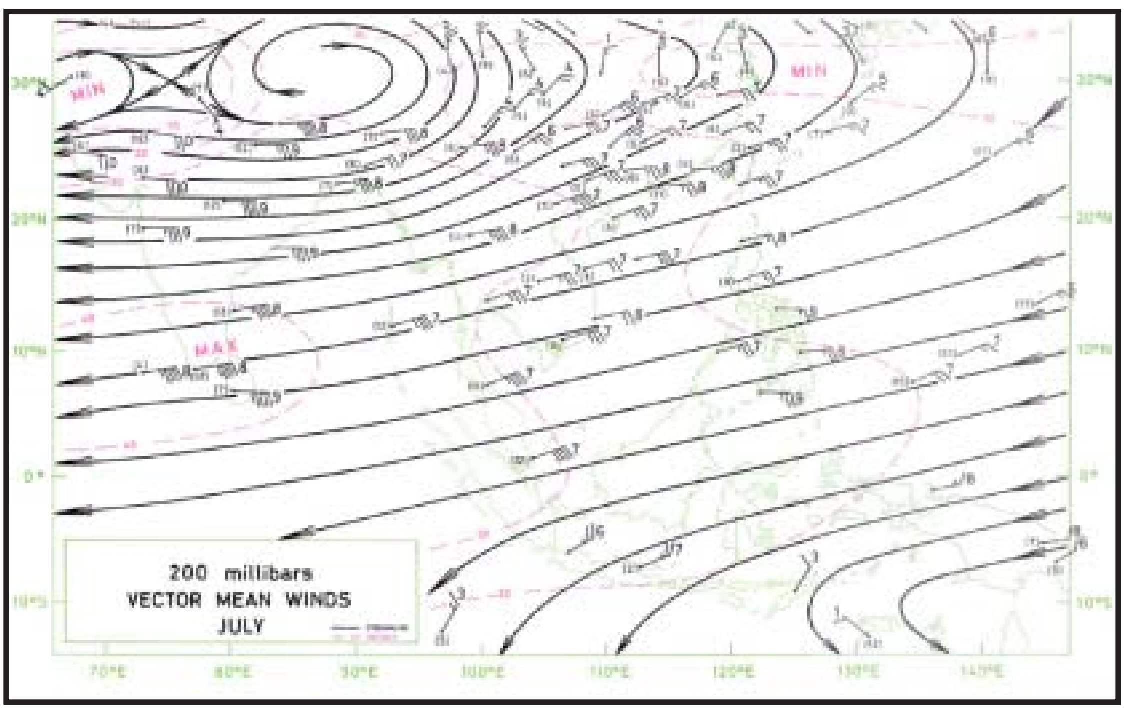

Figure 2-26c-4. Streamline Analysis at 200 mb for July. The full solid lines depict streamlines (arrowheads indicate direction).

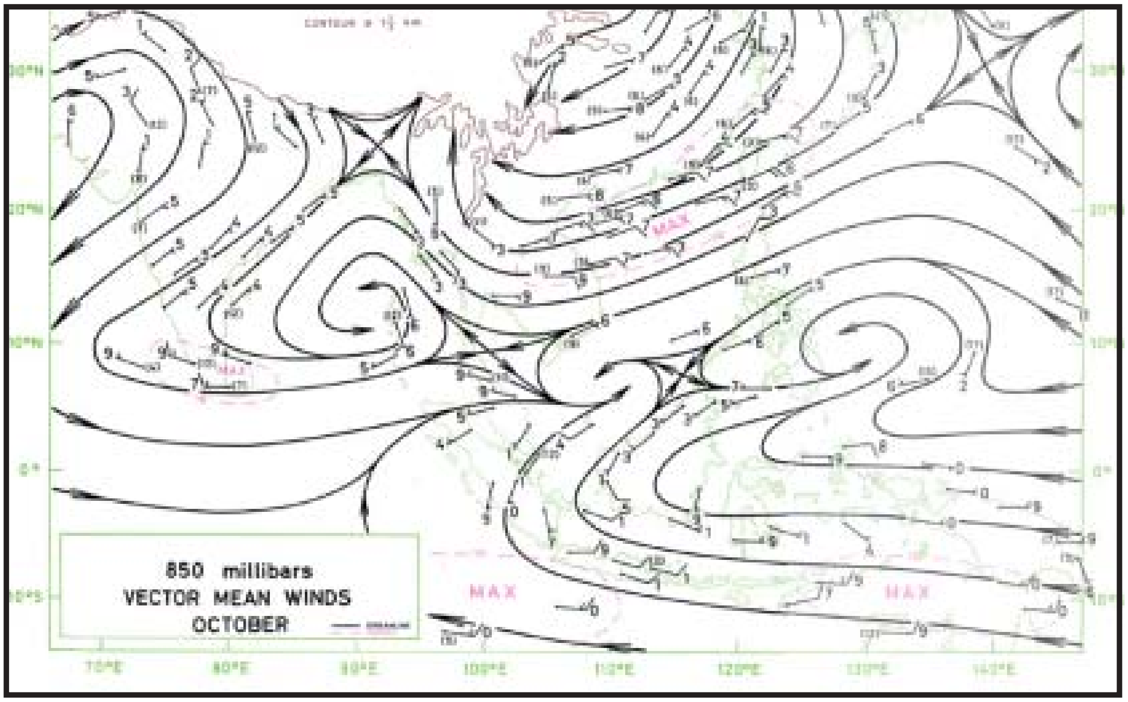

Figure 2-26d-1. Streamline Analysis at 850 mb for October. The full solid lines depict streamlines (arrowheads indicate direction).

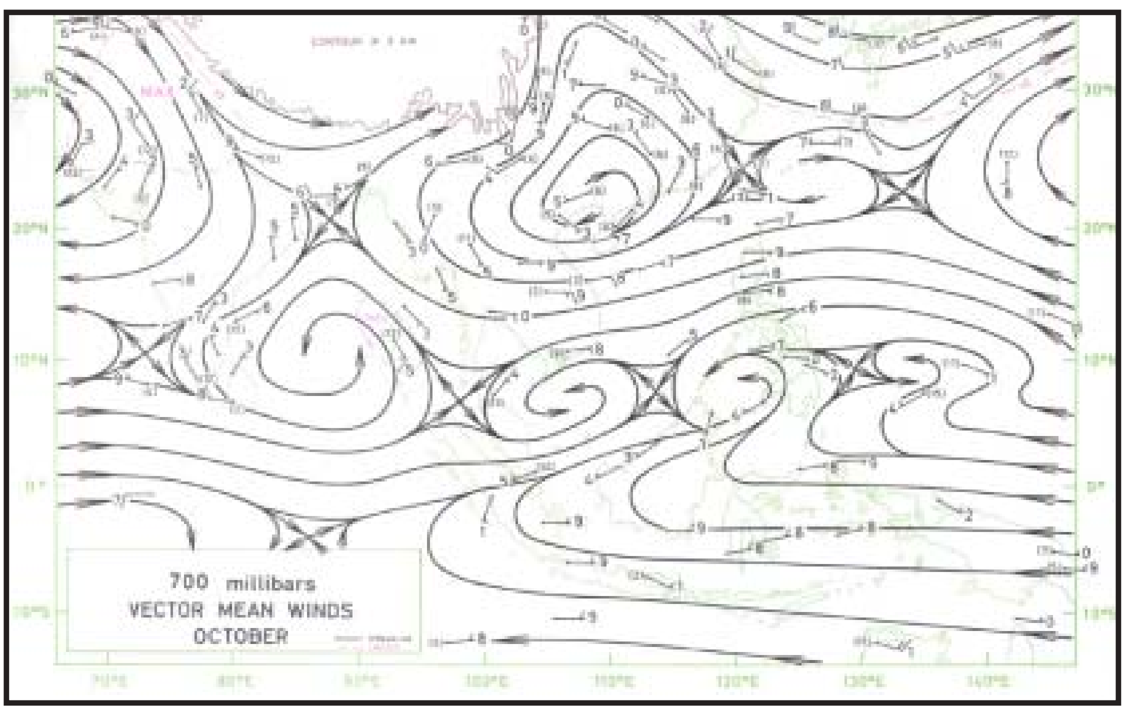

Figure 2-26d-2. Streamline Analysis at 700 mb for October. The full solid lines depict streamlines (arrowheads indicate direction).

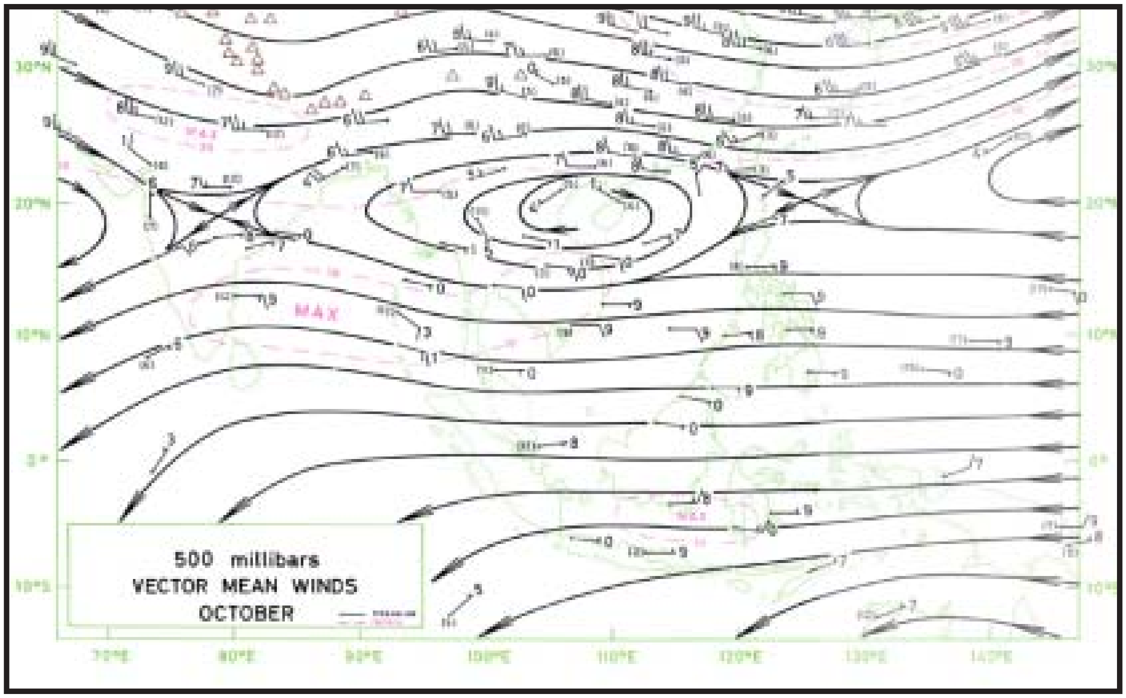

Figure 2-26d-3. Streamline Analysis at 500 mb for October. The full solid lines depict streamlines (arrowheads indicate direction).

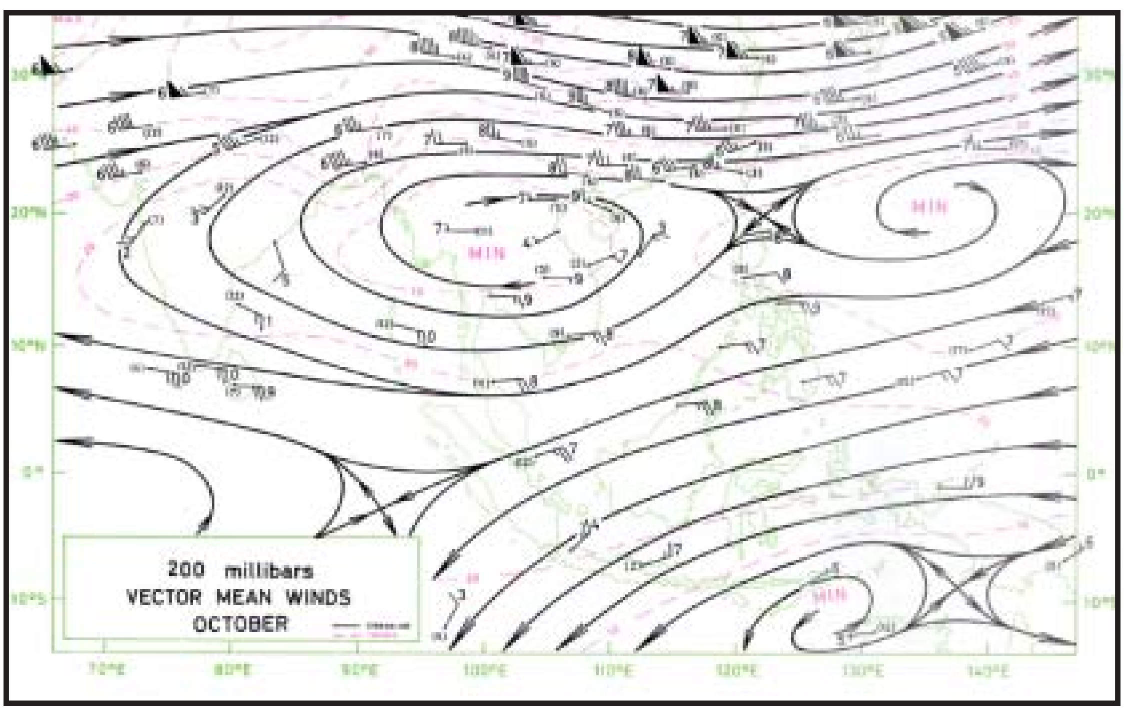

Figure 2-26d-4. Streamline Analysis at 200 mb for July. The full solid lines depict streamlines (arrowheads indicate direction).

monsoon is underway by April. The high pressure area over the Asian mainland at the 850-mb level weakens. The subtropical ridge has begun its northward movement. The NETWC is also moving north. July's pattern shows that southwest monsoon is in progress over the western two-thirds of the region. A southerly wind flow is over the region in the lower levels, and the subtropical ridge axis is around 30° N through 500 mb. The upper-level westerlies have retreated north and weakened, while at 200 mb, the Tibetan high and TEJ have developed. October shows the transition to the northeast monsoon. The Asiatic high is replacing the Asiatic low. The subtropical ridge axis has started to move south. The upper-level westerlies strengthen once again as they shift southward. At 200 mb, the Tibetan high moves and the TEJ dissipates.

Subtropical Ridges. These ridges are upper-level features north and south of the equator with easterly flow between them. Mean annual positions are at 15° N and 10° S, centered at about 130° E. They move north and south with the sun. The ridges provide outflow for the NETWC and tropical cyclone convection. They also provide a steering mechanism for tropical cyclone movement. Ridge movement is a component of the transition to both the northeast and southwest monsoons (southward for northeast, northward for southwest). Ridge location also impacts rainfall during the southwest monsoon. If the ridge extends far enough westward into the western Pacific, a monsoon break occurs. Monsoon breaks lead to a significant increase in precipitation in equatorial western Pacific basin. The subtropical ridges sometimes form anticyclonic cells over the region similar to the one seen at the 200-mb level. The position and strength of these cells depend on the strength and position of the tropical upper-tropospheric trough (TUTT) described below.

Tropical Upper-Tropospheric Trough (TUTT). The TUTT is a buffer zone between two cells of the subtropical ridge. The TUTT enhances the upper-level divergence needed for monsoon rains. It also enhances tropical cyclone development by diverting the upper-level westerlies away from a developing system. An inactive TUTT has an east-west orientation, but takes on a southwest-northeast orientation when active (Figure 2-27). When active, it is associated with extensive convective cloud systems. During active

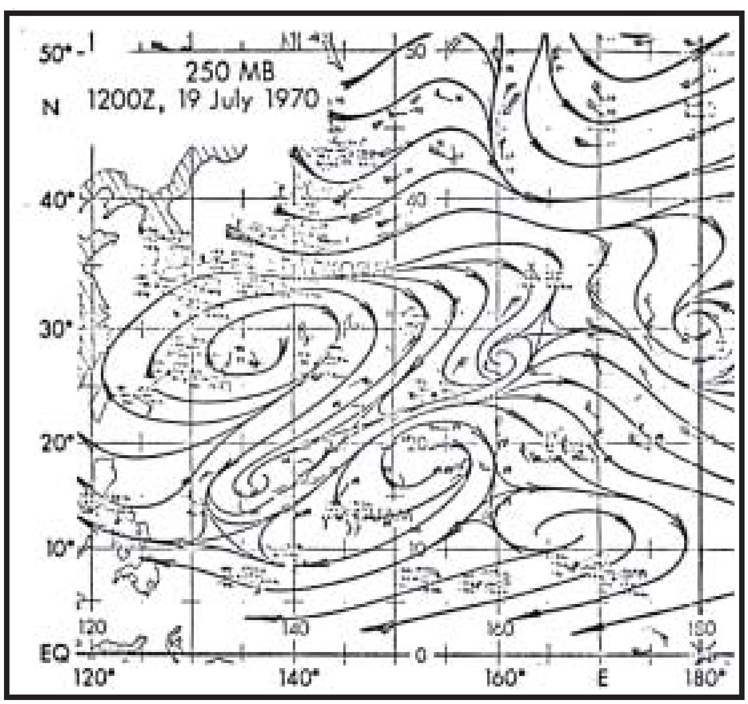

Figure 2-27. Streamline Analysis. Shows an active TUTT.

periods, two TUTTs tend to form in the Pacific. In the western Pacific, the active TUTT does not have a link with mid-latitude systems.

Tibetan High. The Tibetan high intensifies the easterlies south of the Himalayas and creates the TEJ. It also provides upper-air divergence needed for the southwest monsoon rains. Normally it forms at 200-100 mb in April when a high-pressure cell from the South China Sea migrates to the Tibetan plateau. Figure 2-28 shows the mean positions in July and August. A heat low forms on the Tibetan plateau's surface (at 600 mb) and is surrounded by a ring of highs along the plateau rim. The upper-level high is maintained by the plateau's intense heating, by latent heat release from the southwest monsoon rains and by dynamic interaction with the subtropical ridge, which can cause its position to vary. The Tibetan high oscillates with a period of 10-16 days. The northeastward movement of the Tibetan high is required for the establishment of the southwest monsoon. A 1987 study of this movement shows an example on how the process works (Figure 2-29). The numbers represent 5-day periods that starts on 16 April 1987 and ends on 4 July. The abrupt northward jump between Periods 5 and 6 (11-15 May) coincided with the onset of the southwest monsoon. The establishment of the Tibetan high took place during period 14 (20-25 June), when it followed a cell eastward from the Arabian Peninsula. Periods 15 (not shown) and 16 show the Tibetan high splits into two cells, one over central China, the other over northern Iran.

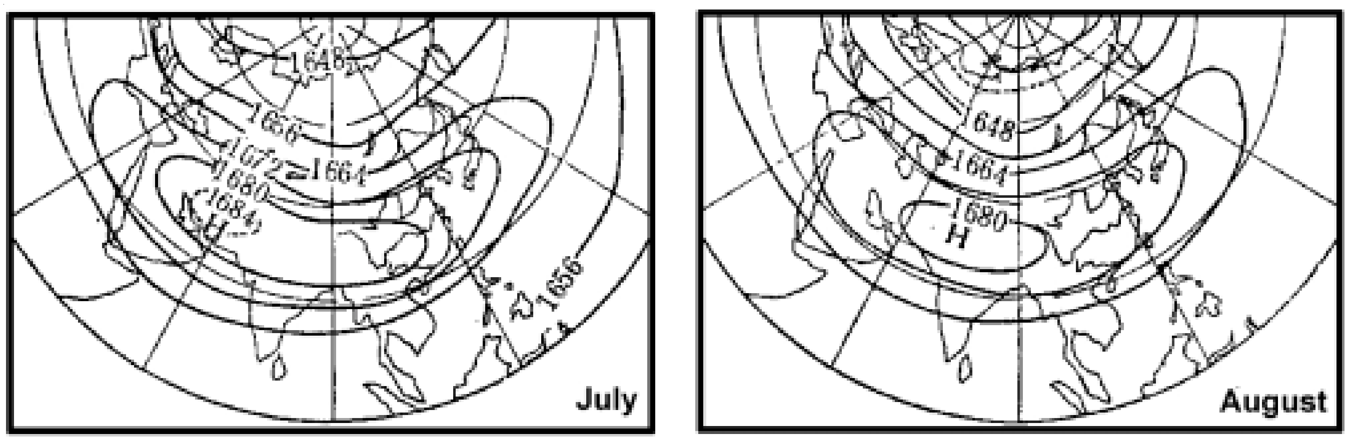

Figure 2-28. Mean 100-mb Charts for July and August (1956-1970). Shows location and strength of Tibetan Anticyclone. (From Murakami, 1974).

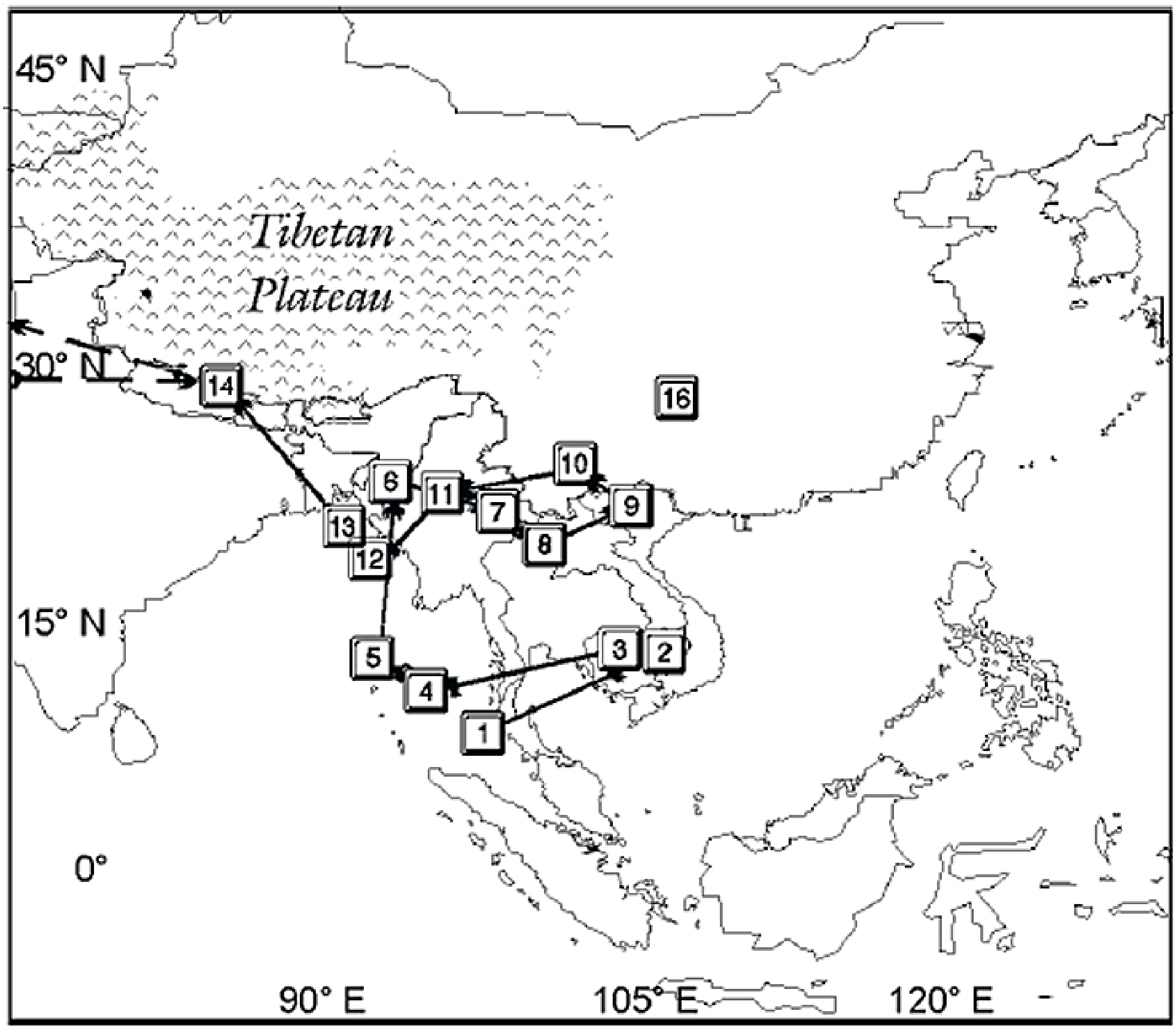

Figure 2-29. Mean Positions of the Tibetan Anticyclone at 200 mb (16 April - 4 July 1979). Depicts movement of the anticyclone after formation. (From He, et al., 1987)

SYNOPTIC FEATURES

Mid-Latitude Disturbances.

Polar Front. Figure 2-30 shows the mean position of the Northern Hemisphere polar front in January and July. The polar front lies on the northern boundary of the western Pacific basin in January, coinciding with the position of the subtropical westerly jet stream. In winter, it is considered the southern boundary of the winter monsoon. Movement of the polar front into the western Pacific basin usually occurs only during a cold surge event. Even then the front will only affect the extreme northern portion of the region as the front quickly undergoes frontolysis as it interacts with the northeasterly trade winds (Figure 2-31). In the Southern Hemisphere, the polar fronts do not affect the western Pacific basin as they rarely move north of 25 S.

Shear Lines. During the winter months, some cold fronts penetrate the tropics with the onset of a cold surge. Although the front quickly undergoes frontolysis through interaction with the northeasterly trade winds, a shear line can still be detected in the low latitudes. Some of them occasionally reach Guam, causing extended periods of low ceilings and poor visibilities. Other shear lines sometimes move as far south as the southern Philippines. If the shear line is well defined and intense, heavy rainfall can be expected during its passage over southern Luzon. If it is weak, expect little precipitation, if any, with its passage.

Cyclogenesis/Storm Tracks. The low-pressure systems that develop over China, and eventually move eastward off the continent, have their origins on the lee side of the Tibetan Plateau over China and Mongolia. After formation, the upper-level westerlies steer the lows eastward along one of four tracks (Figure 2-32). The lows generally do no have any direct impact on the western Pacific basin. They are, however, a part of the process that initiates the cold surges affecting the western portion of the basin. Like the polar fronts, Southern Hemispheric mid-latitude low pressure systems do not affect the southern portion of the western Pacific basin. They rarely move north of 30 S.

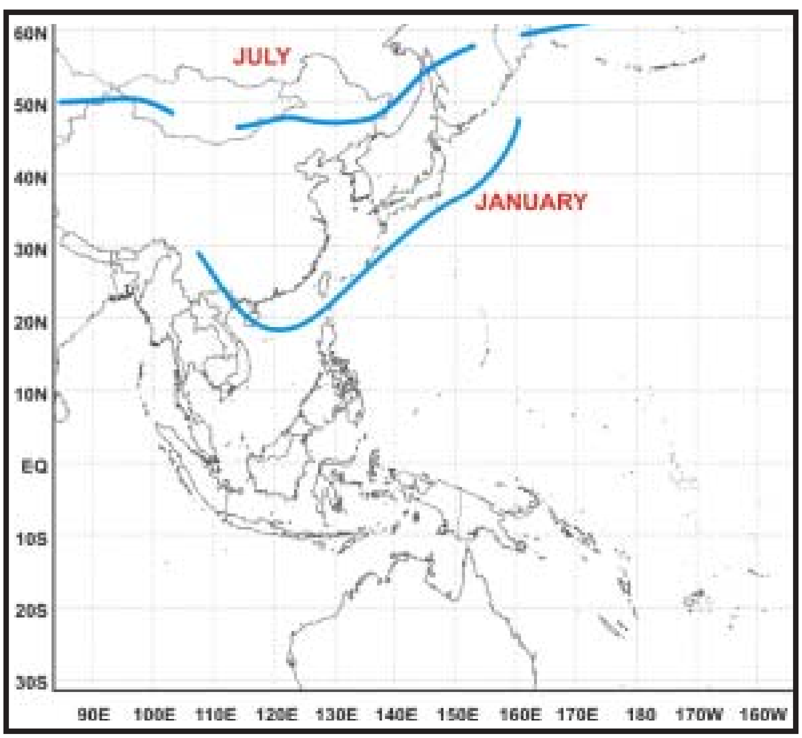

Figure 2-30. Mean January and July Positions of the Northern Hemisphere Polar Front. (From Domros and Gongbing, 1988).

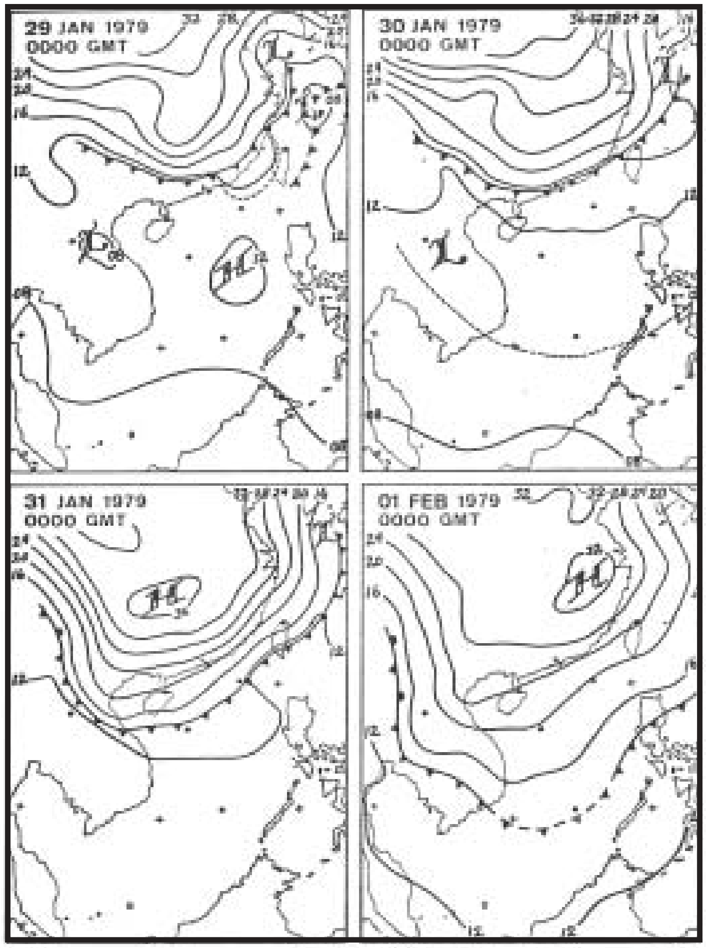

Figure 2-31. Surface Analysis. Depicts sequence of events of the polar front moving into the northern portion of the Western Pacific Basin as a result of a cold surge. (From Chang, et al., 1983).

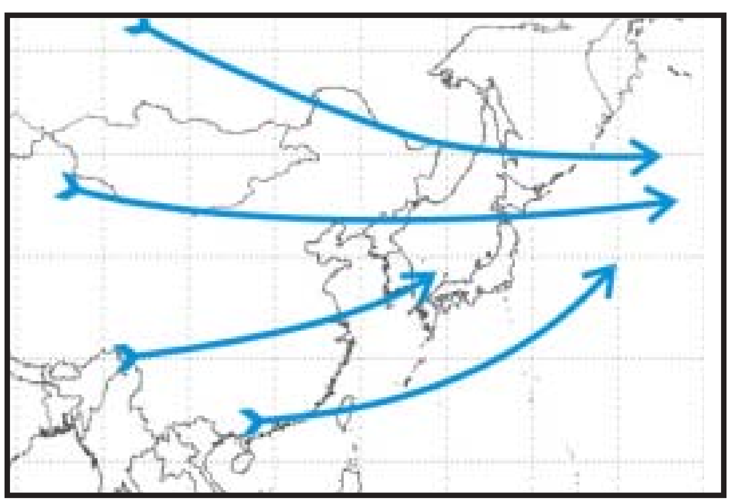

Figure 2-32. Mean Track of Cyclones Exiting the Asian Continent. (From Domros and Gongbing, 1988).

Cold Surges. These occur every 5-20 days during the northeast monsoon. In December and January about four a month reach equatorial South China Sea. Figure 2-33 shows typical streamlines and wind speeds during a cold surge. Cold surges originate with the rapid strengthening of the Asiatic high. Usually a large 24-hour rise center can be traced moving towards the southeast. One also finds a marked, deepening upper trough over the east China coast at the same time. Identification of the leading edge of a cold surge depends upon cyclogenesis off the coast. If cyclogenesis occurs, the surge is associated with a front and is identifiable. If not, the monsoon flow abruptly strengthens and the leading edge of the surge is difficult to determine.

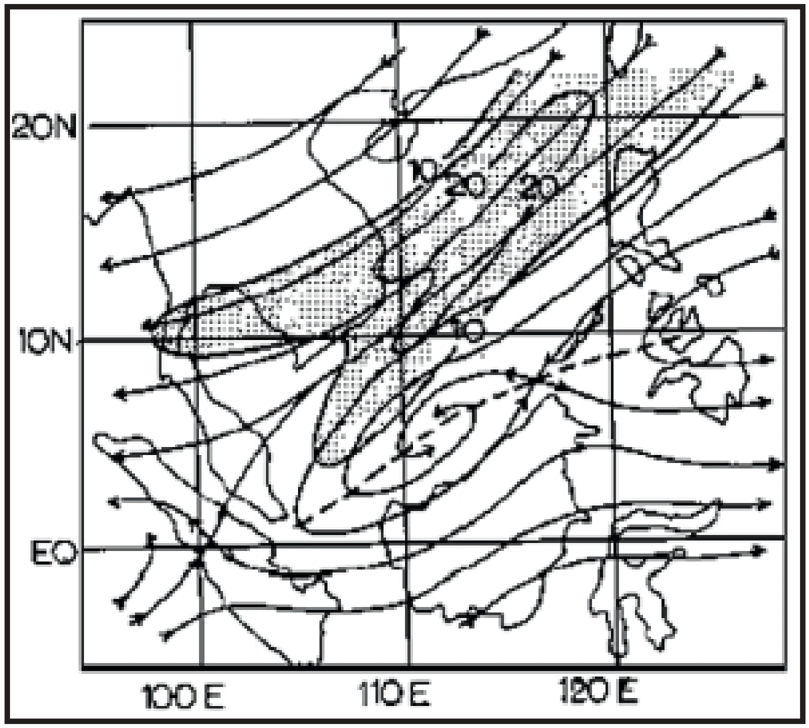

Figure 2-33. Streamlines and Isotachs (m/s) during a Typical Cold Surge. The shaded areas have wind speeds above 10/m/s. The dashed lines indicates the NETWC. (From Lim and Chang, 1981).

A strong cold surge over the South China Sea has two components (Figure 2-34). They depend on how air in central China is diverted around the Nanling ridge. The air to the east of the of the ridge converges with the northeast trades to enhance the low-level northeasterly wind flow. The surge can traverse the entire South China Sea in less than a day. As the cold, dry continental air flow moves south across the South China Sea, it undergoes strong air mass transformation. By the time it reaches northern Borneo, it has been transformed into a warm boundary layer. As a result, the surge initiates considerable convection in the region north of Borneo. In contrast, the air to the west of the ridge does not have as much interaction with the South China Sea. Consequently, the airmass arrives northwest of Borneo cool, which suppresses the westward propagation of convective activity initiated by the freshening winds to the east. The northeast trades behind the surge are strengthened for 3-4 days after the surge's onset, which enhances convection over the western Pacific Ocean. Surges also establish an east-west pressure gradient in the equatorial South China Sea, which triggers east-moving waves in the NETWC. These waves bring heavy rain to northern Borneo.

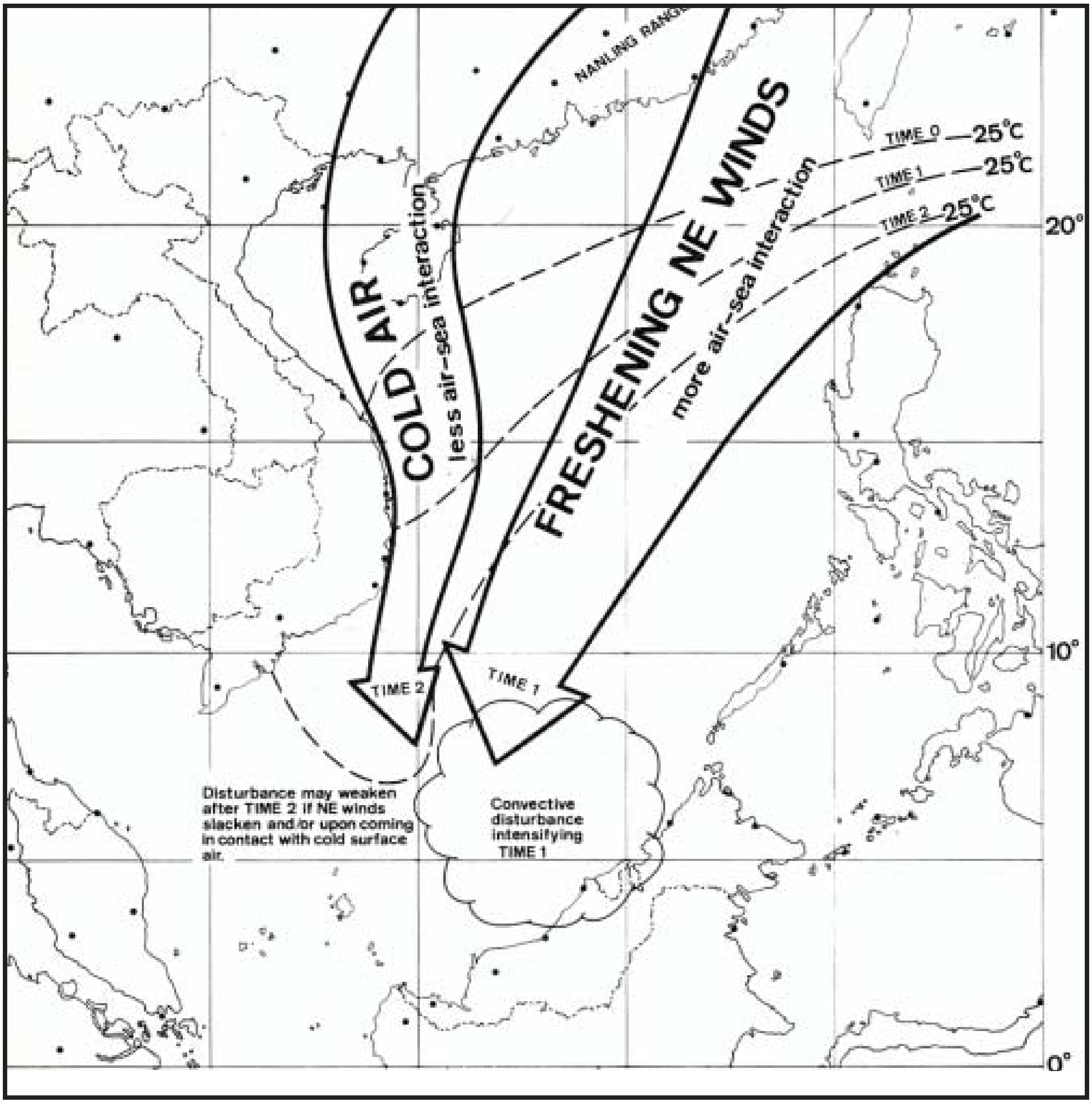

Figure 2-34. Schematic Model Depicting the Time Sequence of a Cold Surge. Shows the position of the 24 C (75F) isotherm at time 1 and 2 (approximately 12-24 and 24-48 hours, respectively following time 0. (From Chang, et al., 1979).

Subtropical Disturbances.

Subtropical Cyclones. Subtropical cyclones usually develop over the South China Sea from February to June, when a pool of cold air is cut off south of the polar westerlies. They primarily affect the oceans north of 10° to 15° N. Rapidly filling tropical cyclones in the South China Sea also spawn them. Subtropical cyclones produce heavy rainfall with the heaviest bands and the strongest surface winds several hundred kilometers from the center. Thunderstorms occur only outside the main circulation. Latent heat release through deep convection may provide enough warming to make them look like tropical cyclones and can actually change a low into one. Also known as "monsoon mid-tropospheric lows" or "mid-tropospheric cyclones," these disturbances are most apparent between 700 and 500 mb and are often not detectable at the surface. Maximum wind speeds are at 600 mb. They are cold-core at low levels and warm-core aloft. Trade winds prevail at the surface away from the center, and a subsidence inversion lies overhead. Trade wind flow is disrupted at the surface near the center. The cyclone may not develop a surface low. Figure 2-35 shows a vertical cross section of a subtropical cyclone.

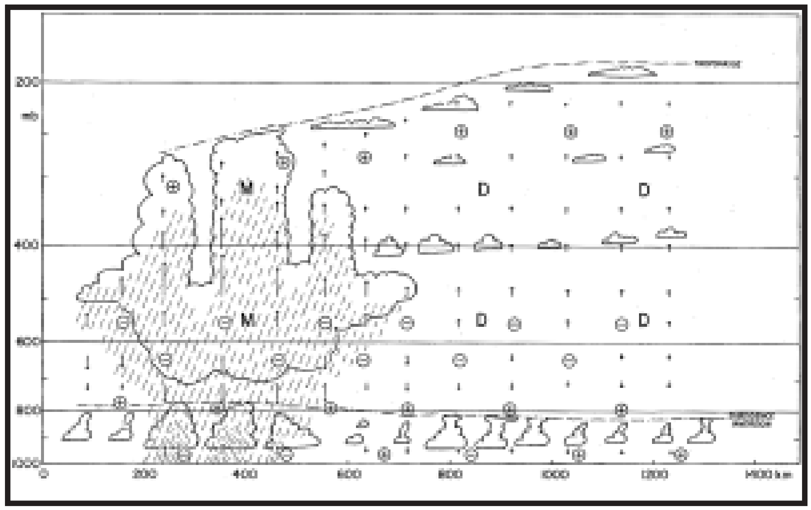

Figure 2-35. Vertical Cross-Section of a Subtropical Cyclone. Divergence is indicated by (+) signs, convergence by (-) signs. Regions of vertically moving air undergoing dry adiabatic temperature changes are denoted by a "D"; regions undergoing moist adiabatic temperature changes are denoted by an "M." (From Ramage, 1995).

Tropical Features.

Equatorial Anticyclone. Also known as "*buffer highs*," these vortices form south of 10° N about 8 times a year in the western Pacific Ocean or the South China Sea (Figure 2-36). They are most prevalent between June and September and last 4-9 days, some as long as 16 days. They are strongest when the Australian high is very strong. Once they develop, equatorial anticyclones tend to move north, sometimes all the way to southern China. They are often associated with major monsoon breaks over southern China as they help establish an anticyclonic flow pattern in the lower levels over the region. They may also affect the movement of tropical cyclones. Studies of several tropical cyclones indicate a strong, north-moving equatorial anticyclone over the western Pacific Ocean or the South China Sea induces a west-moving tropical cyclone to alter course to move east or north.

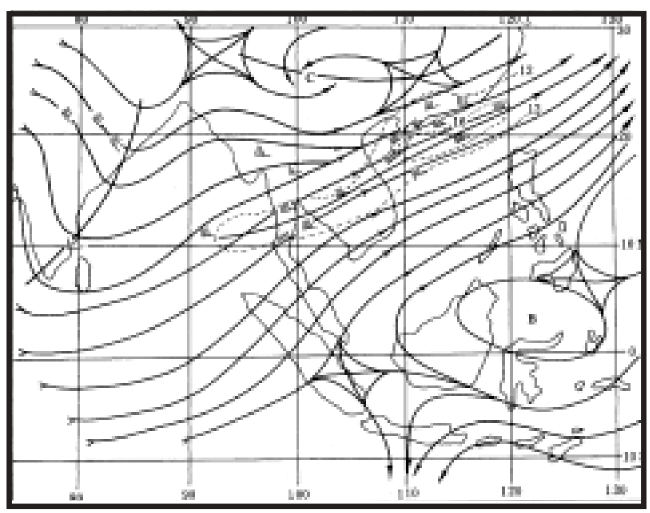

Figure 2-36. Streamlines Analysis. Depicts a buffer ridge (equatorial anticyclone) situated over Celebes Sea. (From Yihui, 1994).

Tropical Waves. Tropical waves are periodic, west-moving disturbances in the easterly flow. They are most identifiable at low levels as weak troughs. Convergent air motion towards the rear of the waves is often associated with convective activity. The waves generally travel roughly 400 miles (640 km) per day. Mid-level winds are lighter than surface winds. A tropical wave model is shown in Figure 2-37, but this classic configuration is often distorted by the NETWC and terrain. They are more active when close to the NETWC.

Tropical Vortices. Vortex is a generic term given to cyclonic cloud and circulation patterns. They are quite common in the tropics and some develop into tropical cyclones. Many dissipate without ever reaching tropical cyclone intensity. Tropical vortices can be ordered in terms of vertical motion (Figure 2-38). In the fine weather vortices (anticyclones, heat lows, and upper-tropospheric cyclones/cold lows), there is subsidence at the middle-tropospheric levels. For the bad weather vortices (tropical cyclones, monsoon depressions, and mid-tropospheric cyclones), the middle-tropospheric air rises.

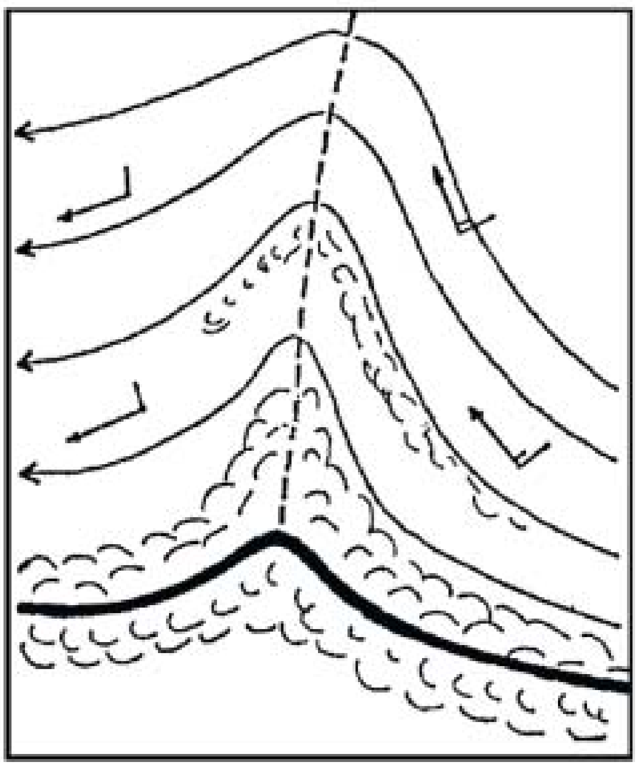

Figure 2-37. Basic Cloud and Wind Pattern of a Tropical Wave. (From Lim and Chang, 1981).

Monsoon Depression. A monsoon depression forms near or equatorward of the NETWC in a strongly baroclinic environment with marked easterly shear. Most rain with this system falls equatorward of the center. The circulation is strongest at 3,000-5,000 feet above the surface. Upward motion is concentrated just south of the surface center (Figure 2-39). The surface center is generally cloud free. The monsoon depression may resemble a tropical cyclone depression on satellite imagery but in a stage well before an eye has formed. The southern South China Sea is the favorite birthplace for monsoon depressions in the western Pacific basin, especially during the northeast monsoon. Movement is generally westward towards the southern Malay Peninsula. Widespread heavy rainfall is common. If a monsoon depression interacts with a southward-moving cold surge, increased low-level convergence causes intense convective activity. A monsoon depression may develop into a tropical depression. The monsoon depression may remain stationary for several days in the vicinity of Malaysia before moving into the Indian Ocean.

Tropical Cyclones. Tropical cyclones are a major threat to the western Pacific basin. They are synoptic-scale systems that develop over tropical waters and have well-organized circulations. Tropical cyclones are warm core systems where the center temperature exceeds that of the surrounding environment and the strongest winds are near the surface. They usually develop from preexisting disturbances and intensify into one of three categories: tropical depressions, tropical storms, or typhoons.

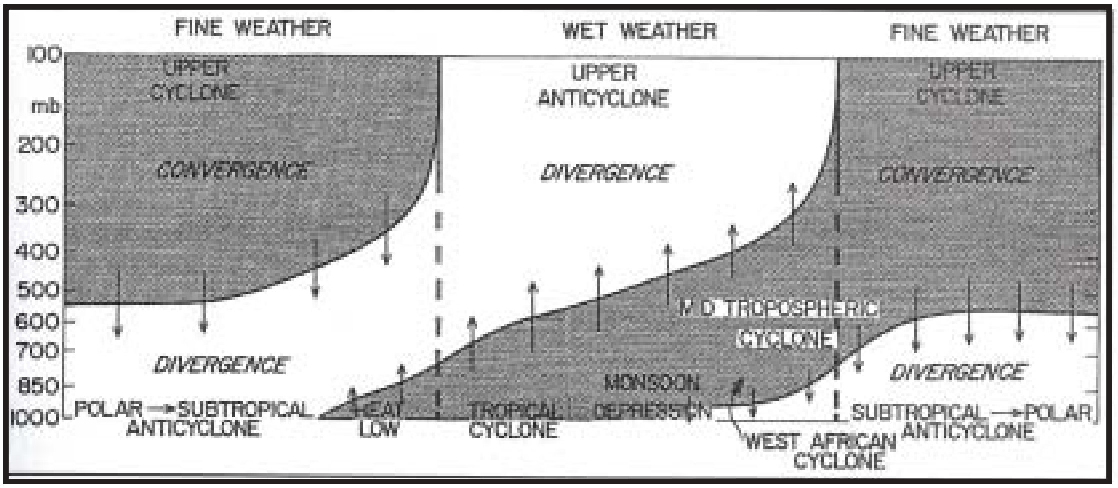

Figure 2-38. Circulation Components of the Atmosphere. Arranged according to weather, divergence, and vertical motion. (From Ramage, 1995).

Tropical Depressions. These are the weakest of the three with sustained wind speeds near the center less than 34 knots. Wind damage is minimal, but heavy rainfall associated with tropical depressions can lead to flooding. Figure 2-40 shows the cloud pattern associated with a tropical depression.

Tropical Storms. Tropical storms are the next category of tropical cyclones and have sustained wind speeds near the center of 34-63 knots. Expect significant wind damage to poorly built structures and major flooding due to heavy rainfall. About 88 percent of the tropical cyclones in the western Pacific basin reach tropical storm intensity. Figure 2-41 shows the cloud pattern associated with a tropical storm.

Typhoons. Typhoons, storms in the final category, are known for the destructive potential of their high winds, rain, and storm tides. Sustained wind speeds near the center are at least 64 knots. Some typhoons have sustained wind speeds over 150 knots. Typhoons with sustained wind speeds of at least 130 knots are called

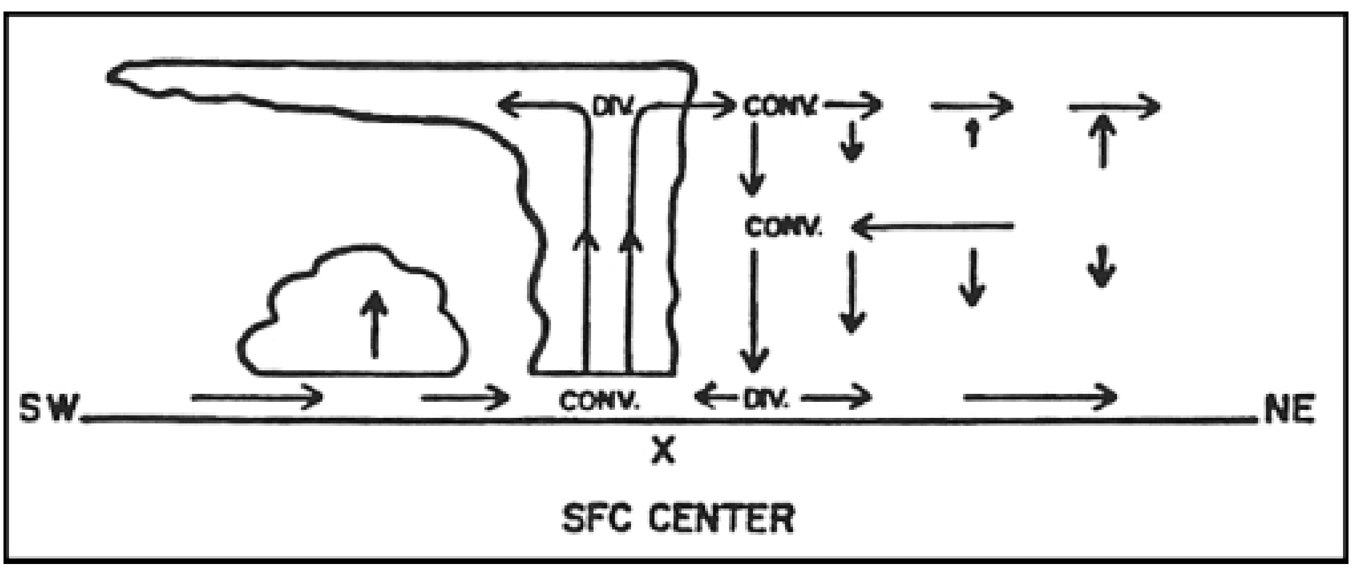

Figure 2-39. Schematic Drawing of the Vertical Circulation across a Monsoon Depression. The asymmetrical cloud field around the depression is attributed to the large horizontal wind shear in the vertical (From Ramage, 1995).

"*super typhoons*." Widespread extensive or catastrophic wind damage is likely, depending upon the typhoon's intensity upon landfall. Ocean vessels have reported severe structural damage when caught in a typhoon. Small vessels have capsized or sunk in heavy seas. Extensive flooding is likely due to the heavy rains and high storm tides. About 49 percent of the tropical cyclones in the western Pacific basin reach typhoon intensity. Figure 2-42 shows the cloud pattern associated with a typhoon.

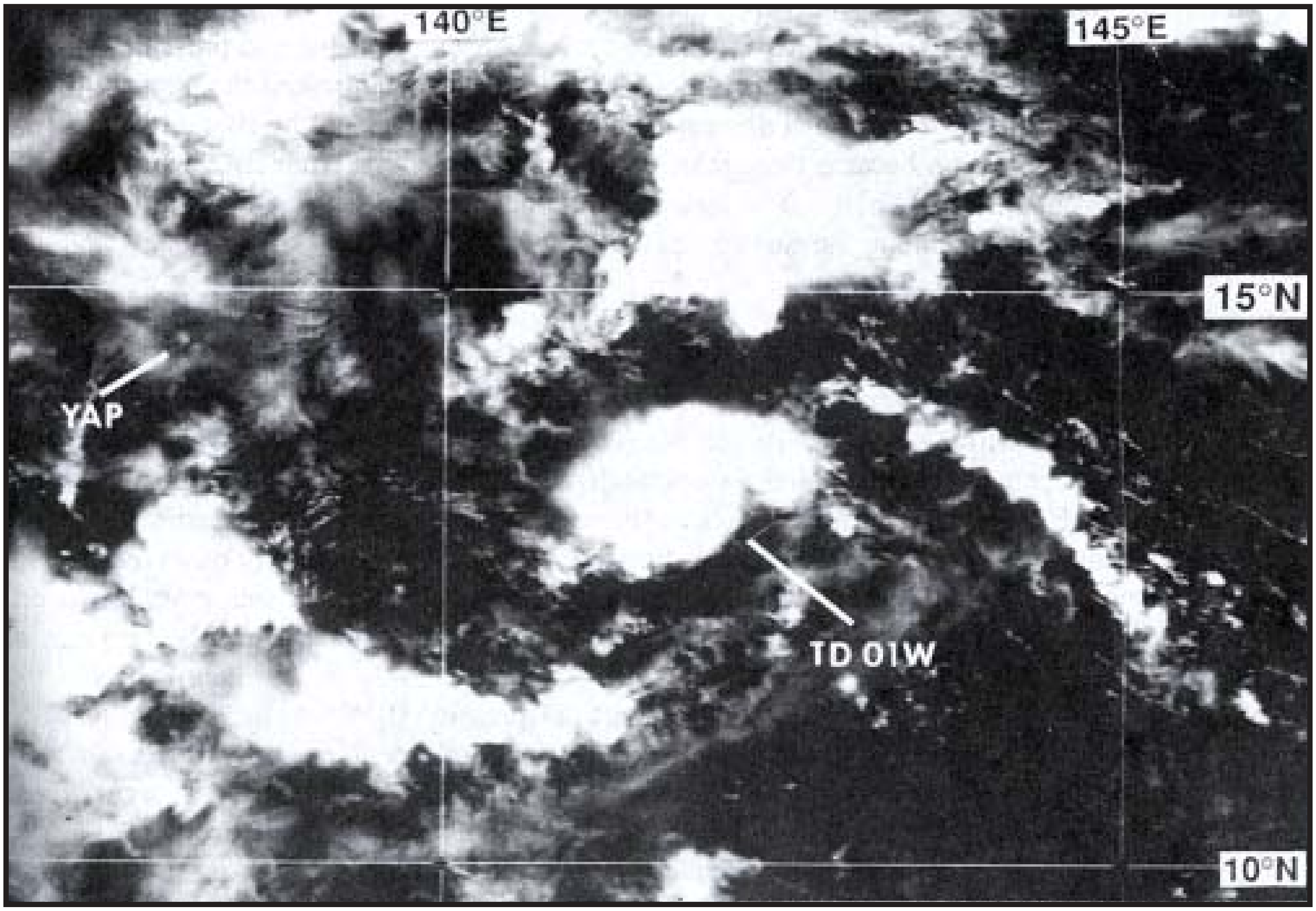

Figure 2-40. Tropical Depression 01W, Located Southeast of Yap Island. This is a visible satellite image taken on 3 Jan 1994. The maximum intensity of this tropical depression was 25 kts. (From JTWC, 1994).

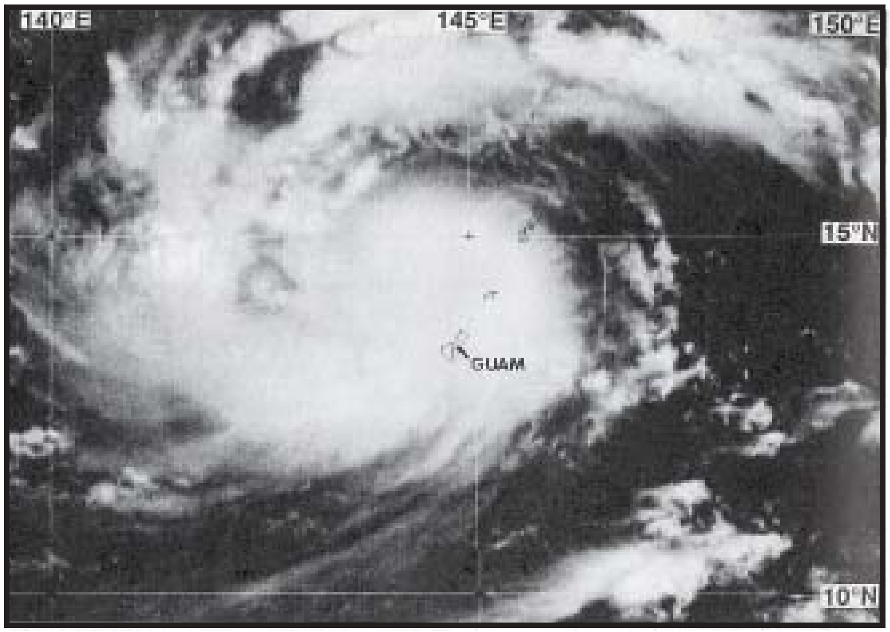

Figure 2-41. Tropical Storm Verne. This is a visible satellite image taken on 18 Oct 1994. Estimated sustained intensity at the time of the image was 50 kts, but Verne later reached a peak intensity of 115 kts. (From JTWC, 1994).

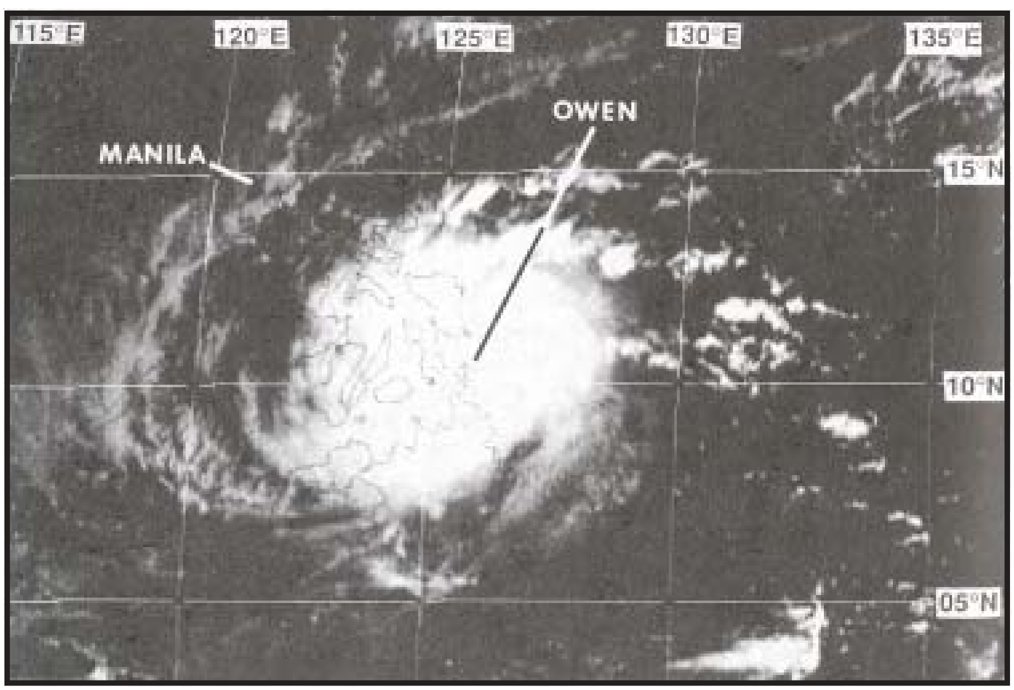

Figure 2-42. Typhoon Owen. This is a visible satellite image taken on 3 April 1994. Owen was at its peak intensity of 75 kts. (From JTWC, 1994).

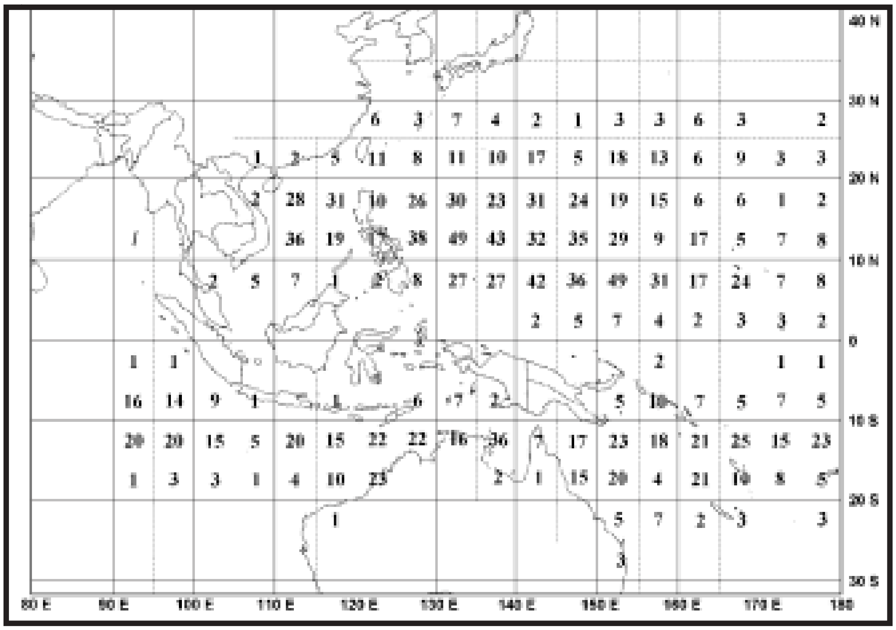

Figure 2-43. Typhoon Cyclone Formation Statistics. The number in each 5-degree square represents the total number of tropical cyclones formed in that area over the period of record. POR for Northern Hemisphere: 1960-1994; for Southern Hemisphere; 1959-1993. (From JTWC, 1994; U.S. Navy, 1994).

The western Pacific basin is the world's most active tropical cyclone region with almost half of the world's annual total (see Table 2-1). Tropical cyclone formation occurs on the equator side of the subtropical ridge axis, generally between 30° N and 25° S (Figure 2-43). The areas highly favorable to tropical cyclone genesis vary from month to month as they are directed related to the position of the NETWC (Figure 2-44).

Table 2-1. Worldwide Tropical Cyclone Summary by Region for 1961 to 1990. (From U.S. Navy, 1994).

Region	Total	Pct
Western North Pacific Ocean (North of Equator, 100E to 180)	848	29.4%
Western South Pacific Ocean (South of Equator, 135E to 180)	304	10.5%
Southeast Indian Ocean (South of Equator, 90E to 135E)	247	8.5%
Southwest Indian Ocean (South of Equator, Africa to 90E)	290	10.0%
North Indian Ocean (North of Equator, Africa to 100E)	308	10.7%
Eastern North Pacific Ocean (North of Equator, East of 180)	522	18.1%
Eastern South Pacific Ocean (South of Equator, East of 180)	75	2.6%
North Atlantic Ocean	295	10.2%
Total:	2889	100.0%

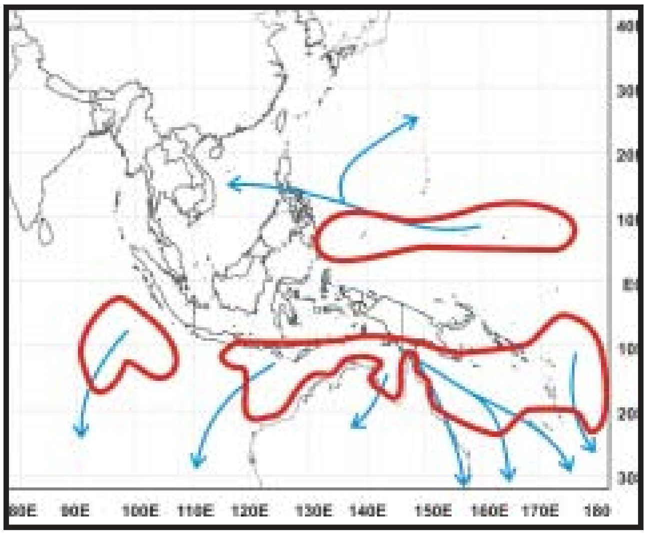

Figure 2-44a. January Tropical Cyclone Formation Areas and Typical Tracks.

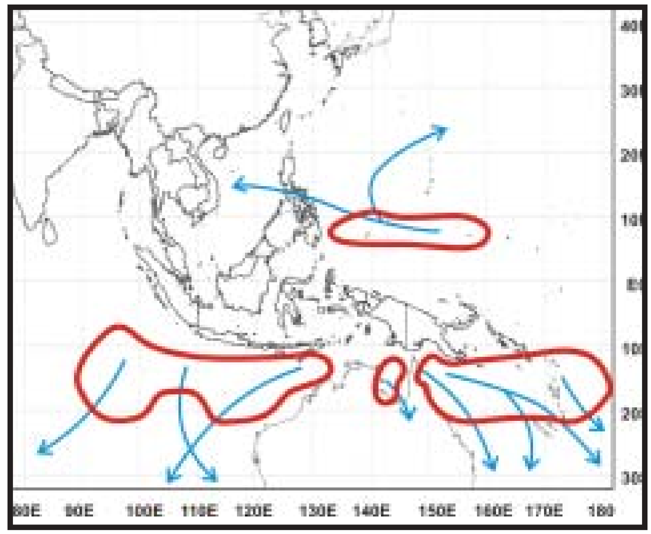

Figure 2-44b. February Tropical Cyclone Formation Areas and Typical Tracks.

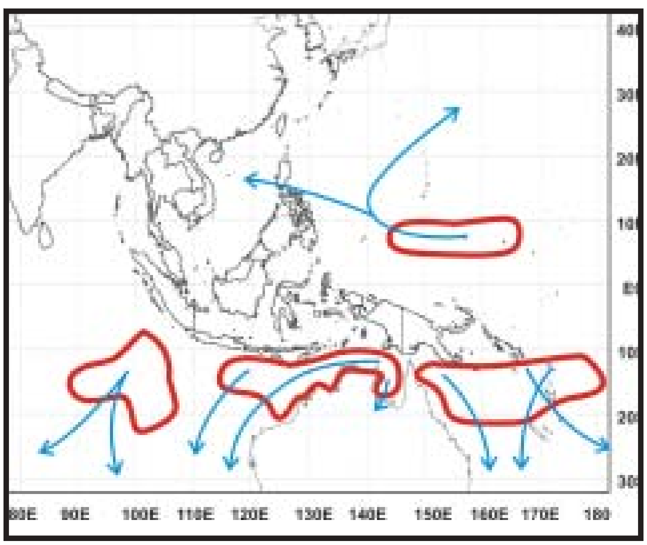

Figure 2-44c. March Tropical Cyclone Formation Areas and Typical Tracks.

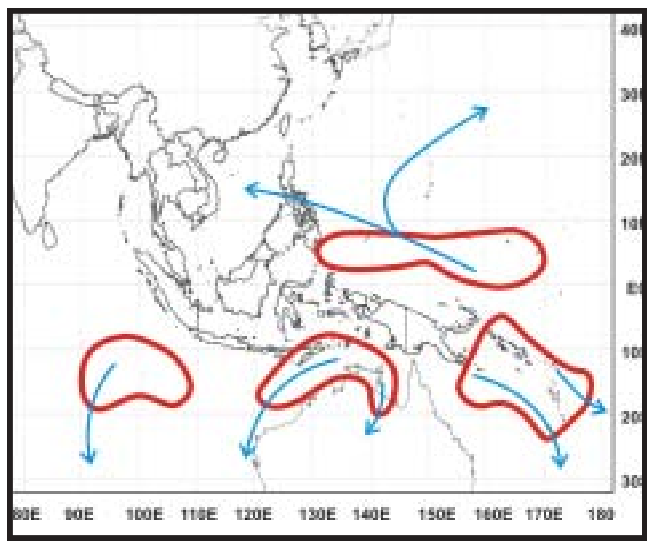

Figure 2-44d. April Tropical Cyclone Formation Areas and Typical Tracks.

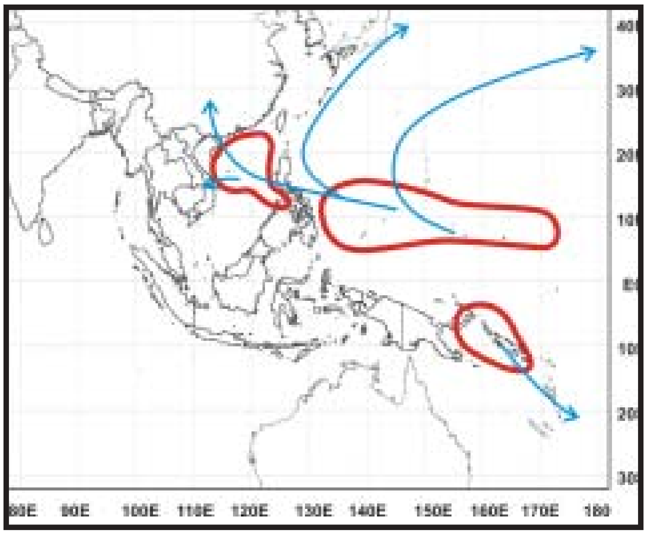

Figure 2-44e. May Tropical Cyclone Formation Areas and Typical Tracks.

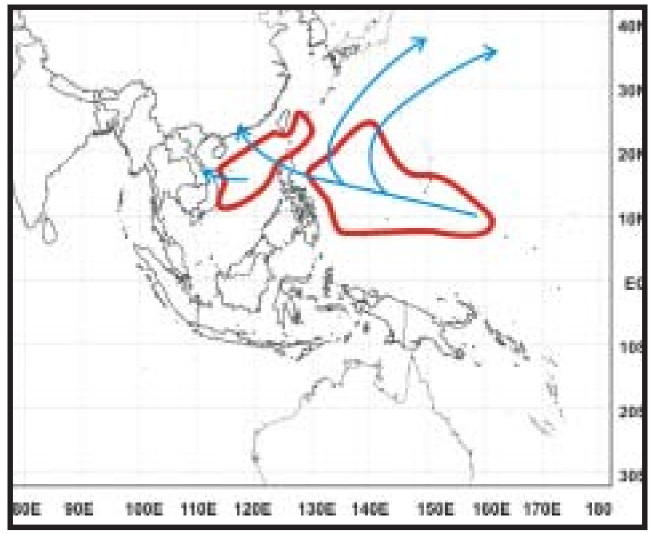

Figure 2-44f. June Tropical Cyclone Formation Areas and Typical Tracks.

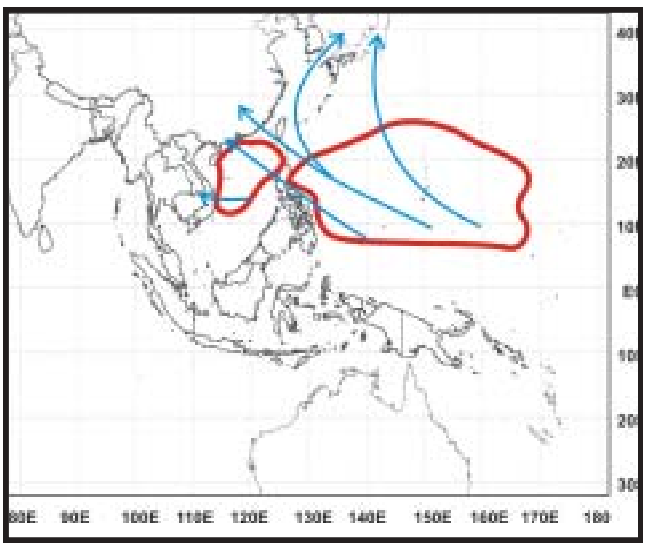

Figure 2-44g. July Tropical Cyclone Formation Areas and Typical Tracks.

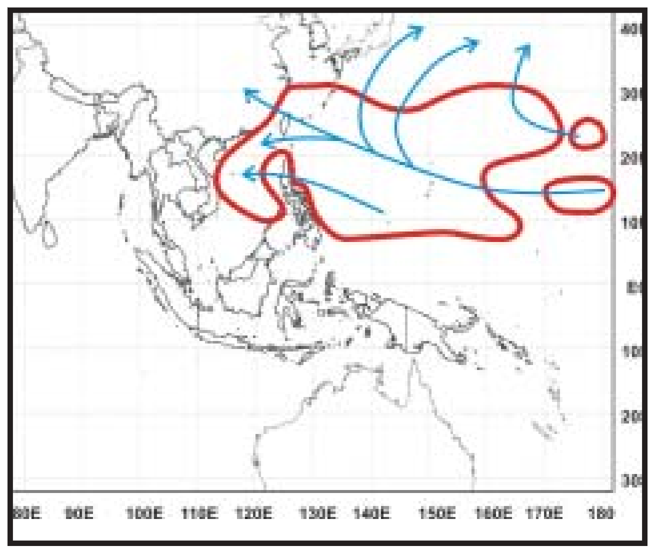

Figure 2-44h. August Tropical Cyclone Formation Areas and Typical Tracks.

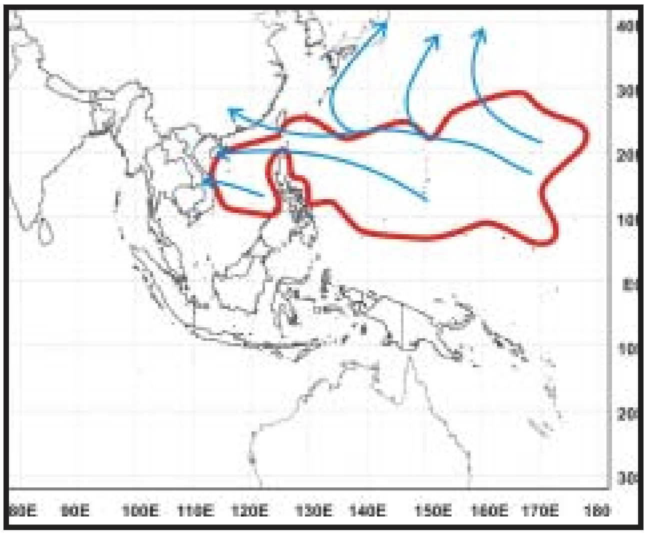

Figure 2-44i. September Tropical Cyclone Formation Areas and Typical Tracks.

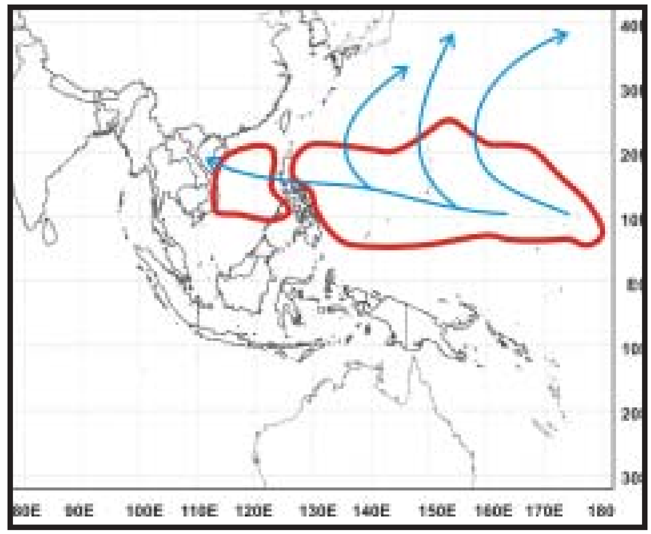

Figure 2-44j. October Tropical Cyclone Formation Areas and Typical Tracks.

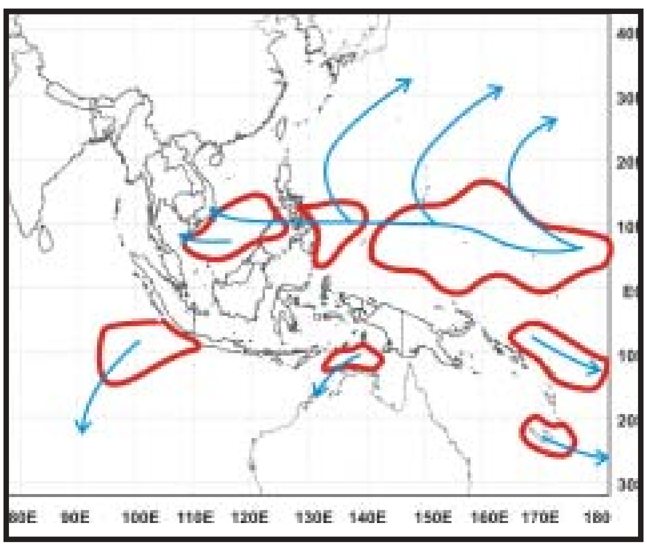

Figure 2-44k. November Tropical Cyclone Formation Areas and Typical Tracks.

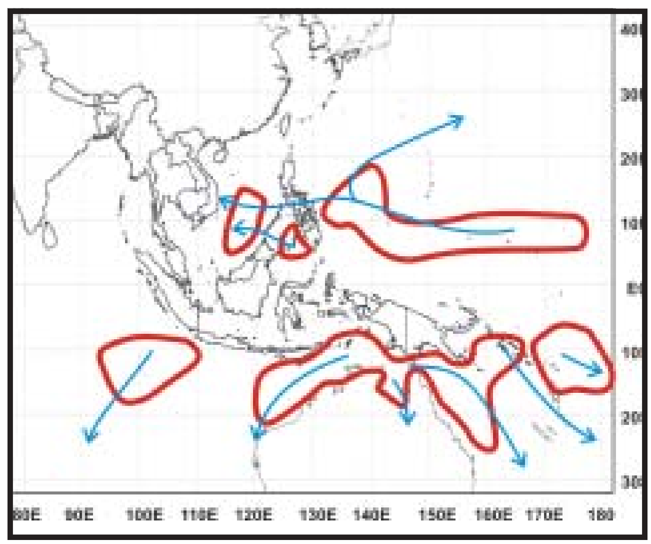

Figure 2-44l. December Tropical Cyclone Formation Areas and Typical Tracks.

The western North Pacific Ocean (Figure 2-45) averages about 31 tropical cyclones per year. Tropical cyclones occur all year with the most activity between May and December and the peak in August (Figure 2-46). The position and intensity of the subtropical ridge determines tropical cyclone movement. It is generally from east to west, though northward movement will occur if there is a weakness in the ridge induced by a mid-level trough north of the ridge. Once a north-moving tropical cyclone pushes north of the ridge axis, recurvature to the northeast, along with forward acceleration, is likely as the system comes under the

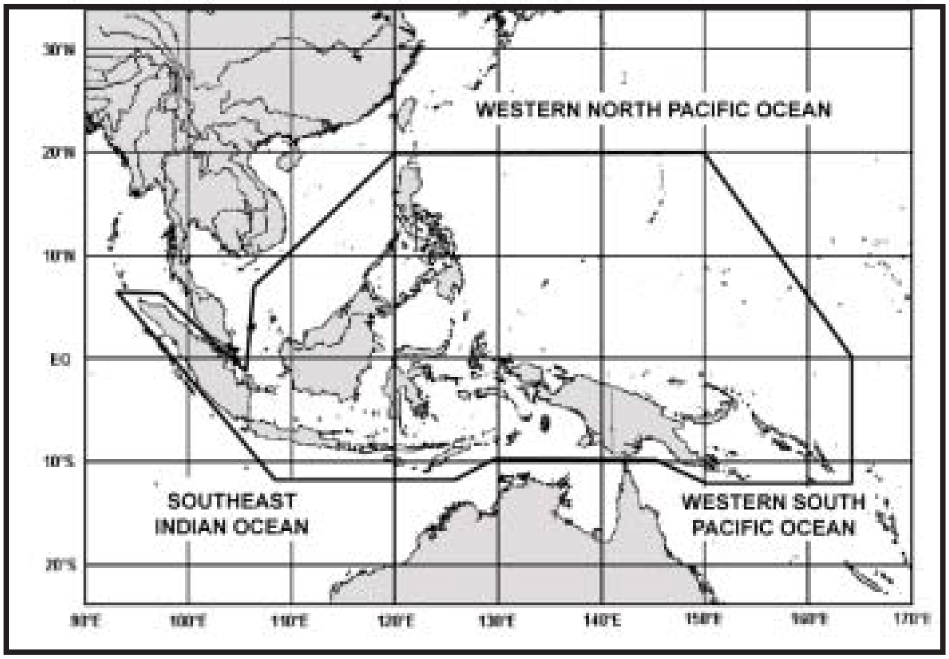

Figure 2-45. Western Pacific Basin Outline with Tropical Storm Region. The area within the block is favored for tropical cyclone activity.

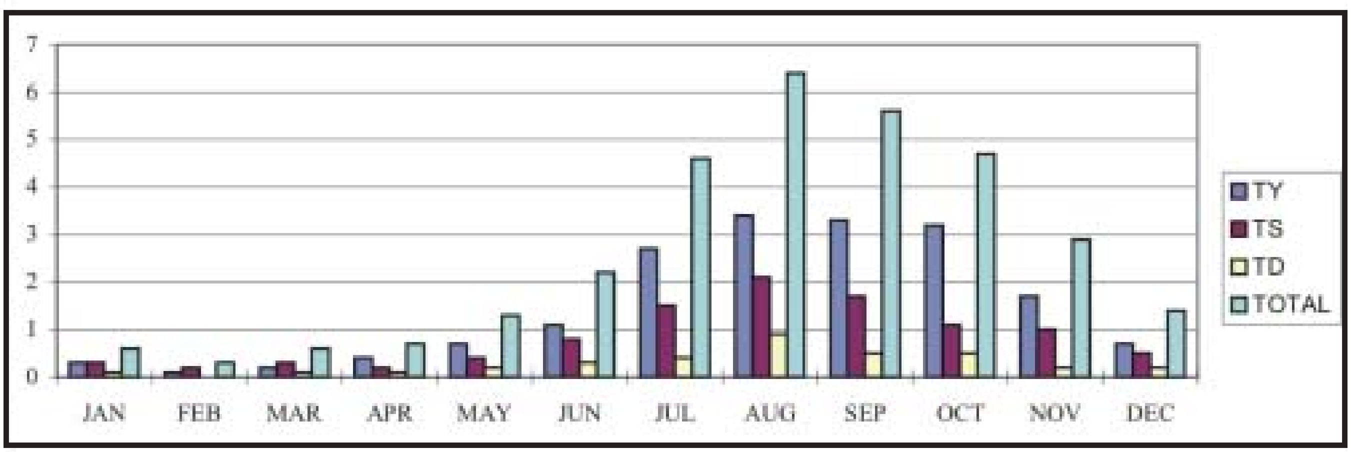

Figure 2-46. Mean Monthly Tropical Cyclone Distribution, Western North Pacific (1960-1964). (From JTWC, 1994).

upper-level westerlies. Many islands in the western Pacific basin are affected by tropical cyclones.

The western North Pacific also has the highest number of tropical cyclones in the world that reach "super typhoon" intensity (130 kts +): an average of nearly four per year (Figure 2-47). It is also where the tropical cyclone with the lowest recorded central pressure on record (870 mb) occurred with Supertyphoon Tip in October, 1979 (Figure 2-48).

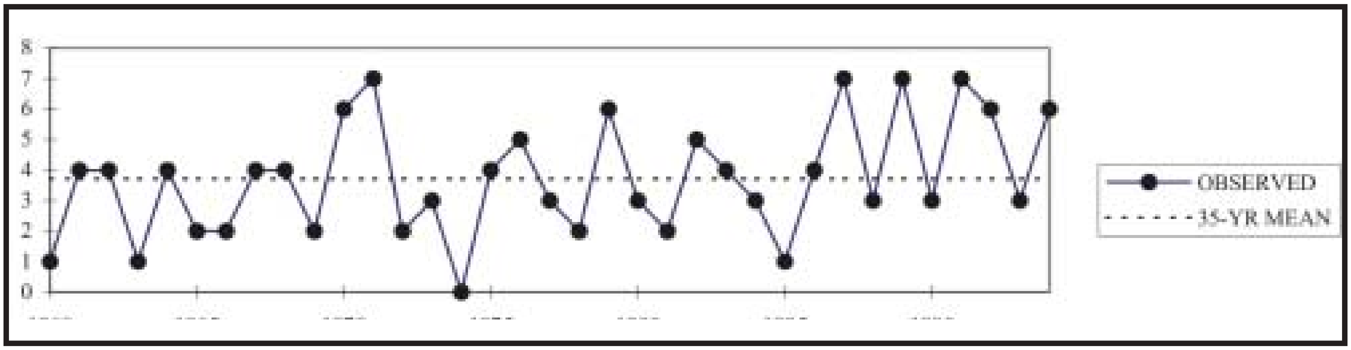

Figure 2-47. Number of Super Typhoons in the Western North Pacific (1960-1994). (From JTWC, 1994).

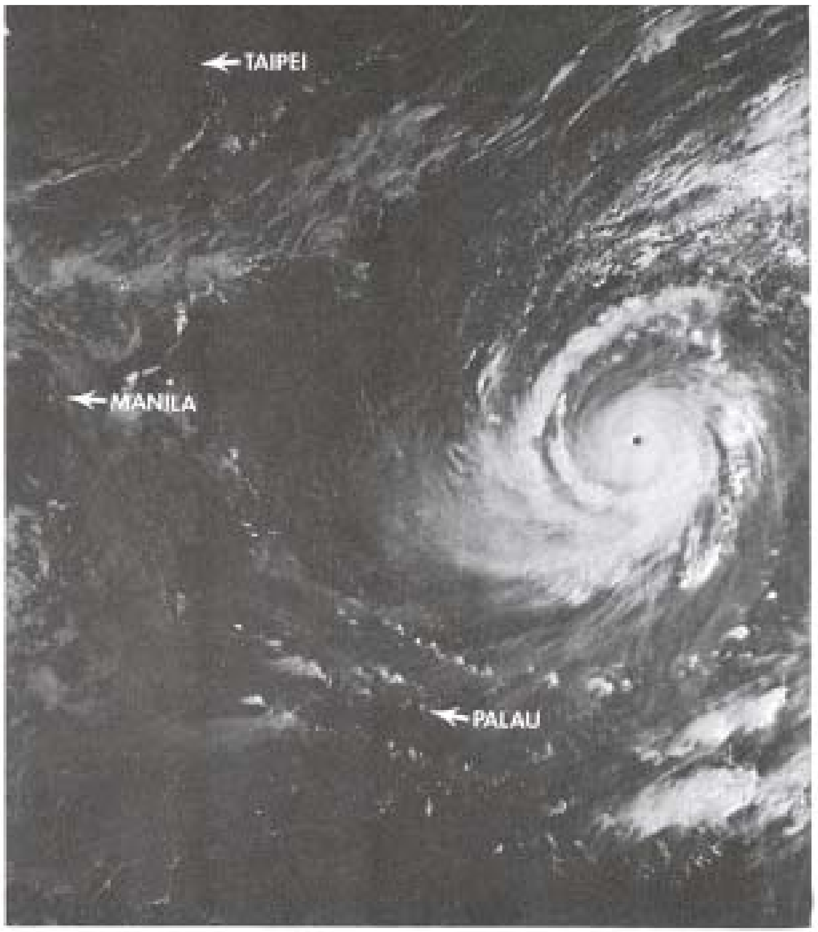

Figure 2-48. DMSP Imagery Taken of Super Typhoon Tip on 12 Oct 1979 at 0012Z. Tip had the lowest sea-level pressure ever recorded in a tropical cyclone: 870 mb. (From JTWC, 1994).

The western South Pacific Ocean is the world's fourth most active tropical cyclone region and averages nearly 10 per year. The season for this region runs from November through July; it peaks in February (Figure 2-49). Since the 200-mb subtropical ridge is centered between 10° S - 15° S most of the year, cyclones move south of the ridge axis towards the southeast.

The southeast Indian Ocean averages 7 tropical cyclones per year from November through May (Figure 2-50). Movement is generally towards the southwest; most systems eventually recurve southeastward as they move south of the ridge axis. Some tropical cyclones develop in the Banda and the Arafura Seas where forward movement takes them near Timor and the islands between the Timor, Banda, and the Arafura Seas.

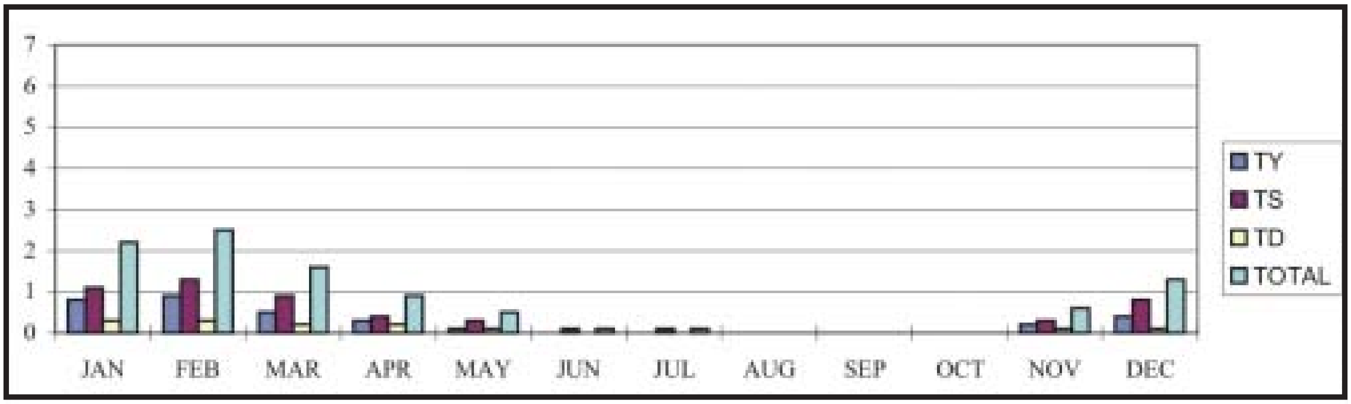

Figure 2-49. Mean Monthly Tropical Cyclone Distribution, Western South Pacific (1959-1993). (From JTWC, 1993; U.S. Navy, 1994).

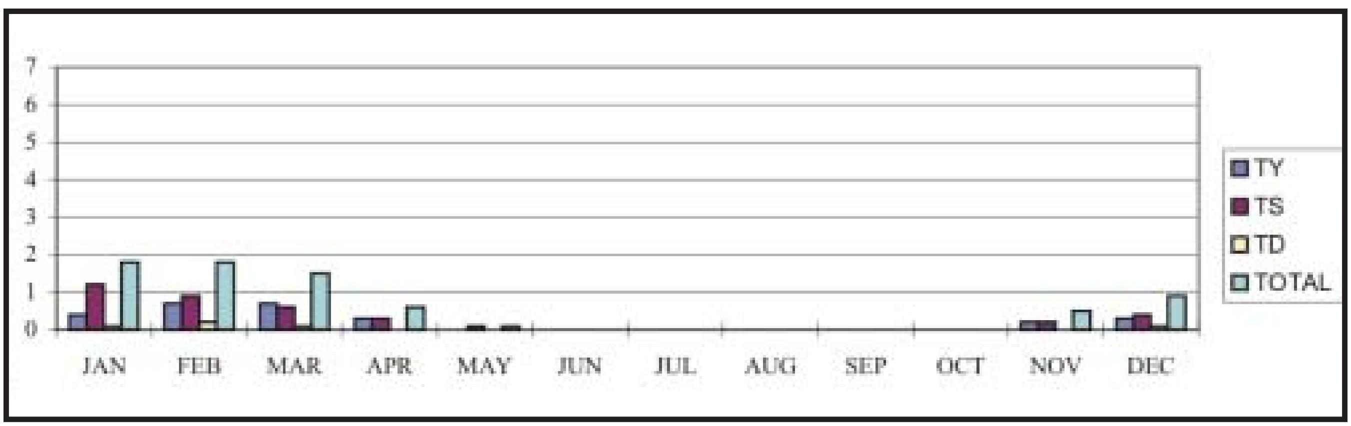

Figure 2-50. Mean Monthly Tropical Cyclone Distribution ,Southeast Indian Ocean (1959-1993). (From JTWC, 1993; U.S. Navy, 1994).

There are occasions when the formation of a tropical cyclone near the equator may coincide with or trigger the development of a “twin” tropical cyclone on the other side of the equator (Figure 2-51). This event occurs when a branch of the NETWC forms on each side of the equator in the western Pacific, usually from November to May (Figure 2-52). Disturbances form with both branches of the NETWC and may develop into tropical cyclones if a westerly wind surge moves into the area along the equator.

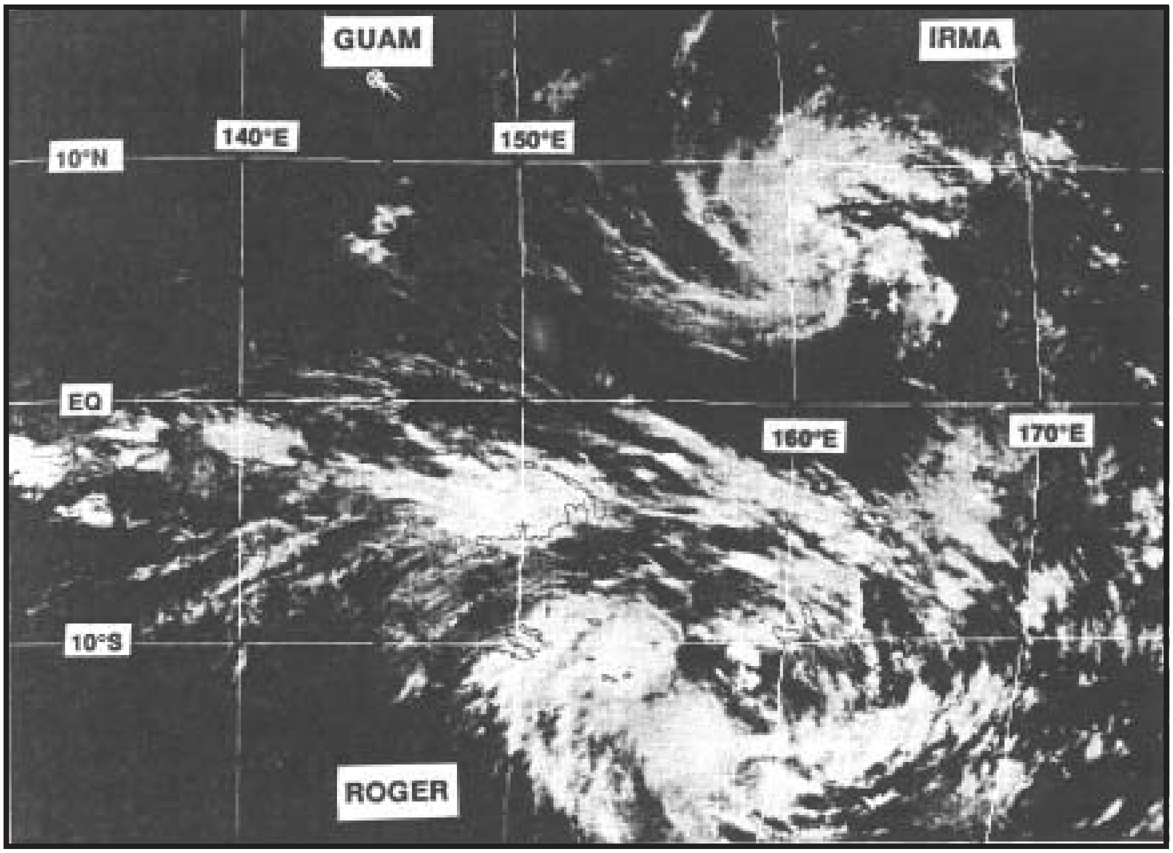

Figure 2-51. Infrared Imagery of Developing Tropical Cyclone Twins, Irma and Roger. Both systems were tropical depressions with estimated sustained intensities of 25 knots when this image was taken. (From JTWC, 1993; U.S. Navy, 1994).

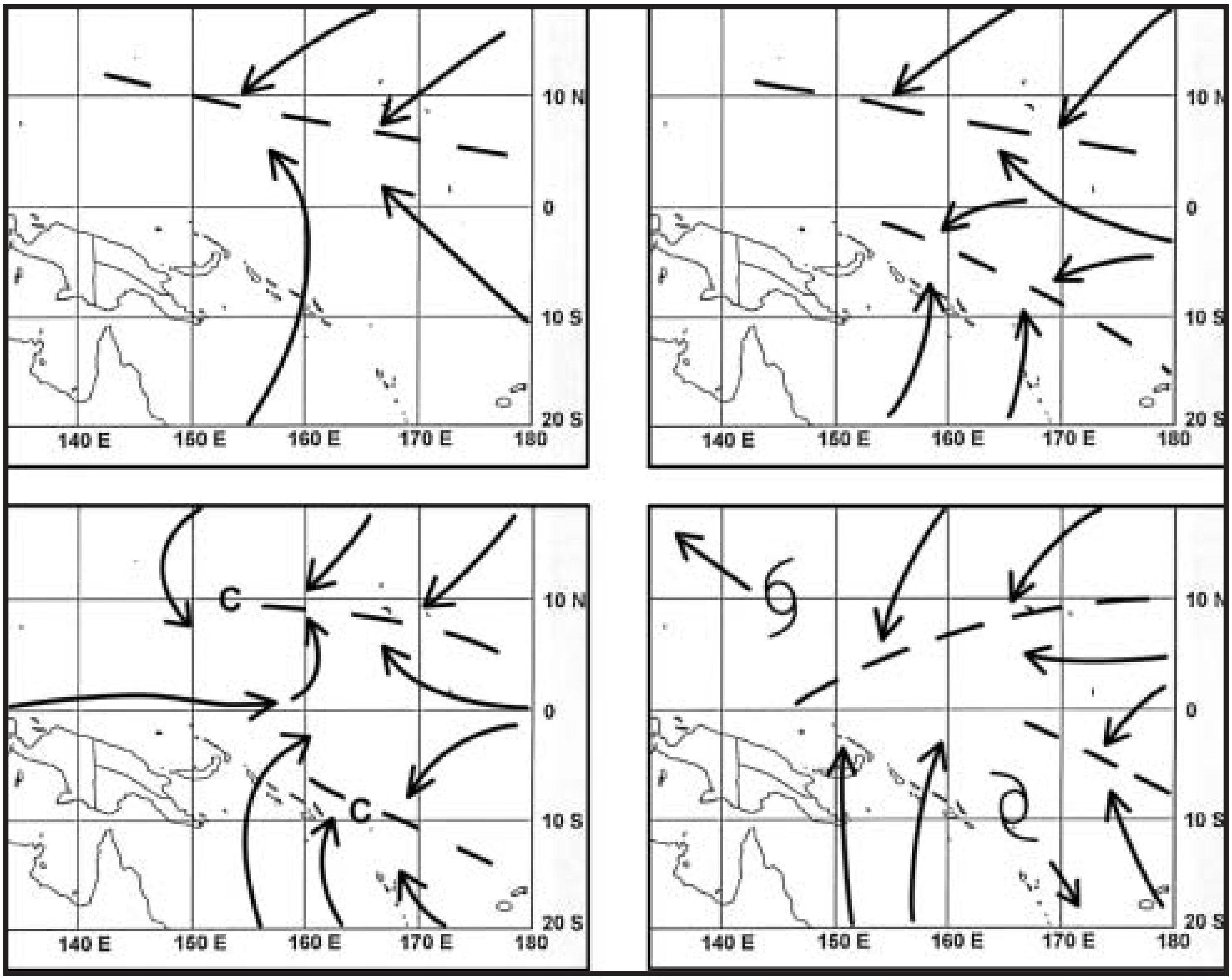

Figure 2-52. Formation of Tropical Cyclone "Twins." The figure shows the sequence of events leading to the formation of tropical cyclone "twins." A. The NETWC sets up north of the equator. The dashed line indicates the NETWC with arrows depicting surface wind patterns. B. A second branch of the NETWC sets up south of the equator. C. A westerly wind surge moves into the region along the equator, indicating a low-pressure system within each branch of the NETWC. D. Tropical cyclones develop from the lows, then move out and away from the NETWC. (From Ramage, 1995; Keen, 1982).

Figure 2-53 is the analysis of the low-level wind field before the formation of the tropical cyclone twins depicted in Figure 2-51. Appendix A contains additional tropical cyclone climatological information.

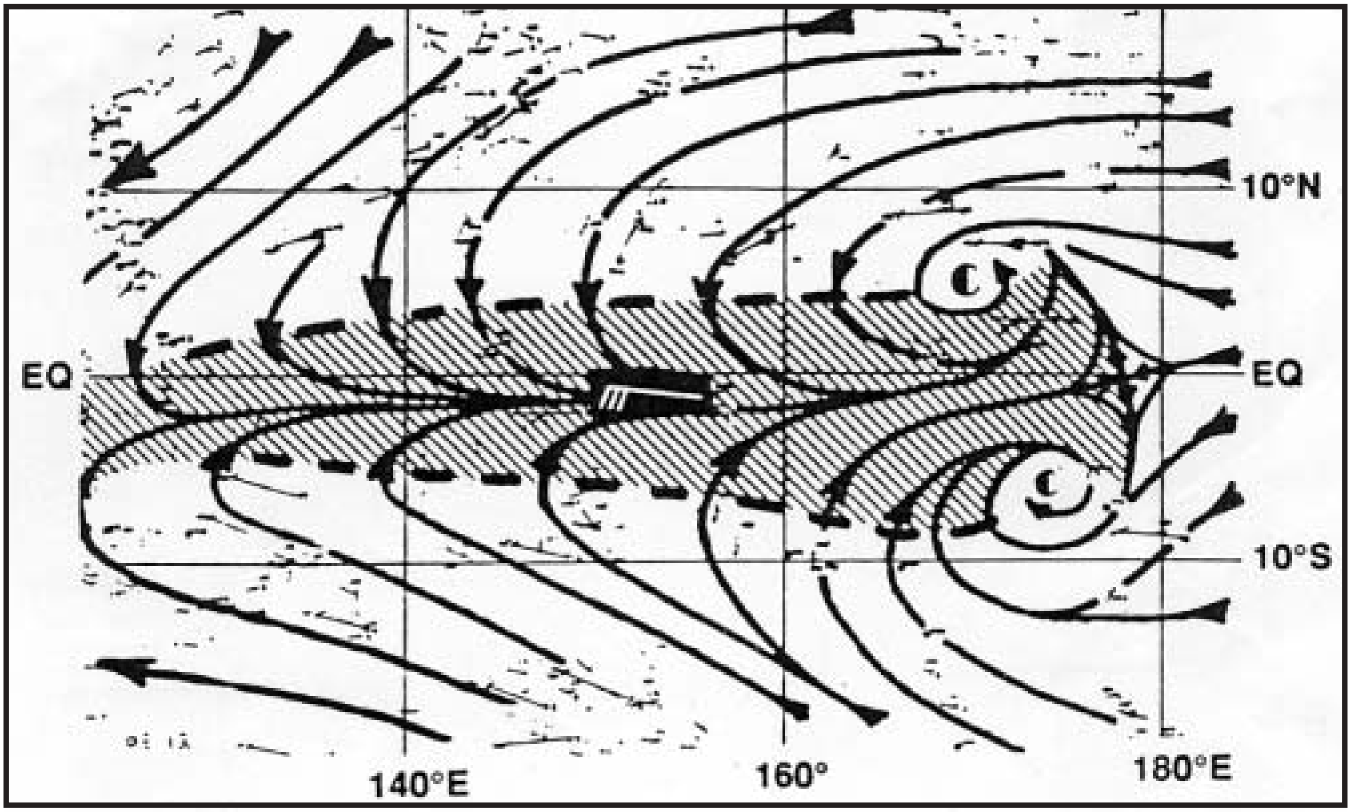

Figure 2-53. Streamline Analysis of the Low-Level Wind Field at 081200Z March 1993. Shaded region shows area of westerly wind flow. Surface ship report of 30 knots near the equator at 155E indicated that an equatorial westerly wind burst had commenced. The cyclonic circulation centers late became the tropical cyclone twins--Irma (02W) and Roger (22P), shown in Figure 2-51. (From JTWC, 1993).

Cloud Features.

Cloud Clusters. Cloud clusters account for a significant portion of the regional rainfall during the year. They are usually found equatorward of the trade wind maximum. They consist of widespread stratiform cloud decks capped by cirrus shields, with rainfall concentrated in embedded convection (Figure 2-54). Formed and maintained by a steady low tropospheric convergence, cloud clusters can last 1-3 days and are 185-620 miles (300-1,000 km) in diameter. They undergo diurnal intensity fluctuations as they move with the low-level tropospheric wind flow. Some clusters eventually evolve into tropical cyclones.

Mesoscale Convective Complexes (MCCs). Tropical MCCs can occur anywhere within the western Pacific basin, they are most frequent in the equatorial region. The preferred locations are off the northwest coast of Borneo and along the western coast of New Guinea. They occur throughout the year in the equatorial region but are commonly limited to the warm season away

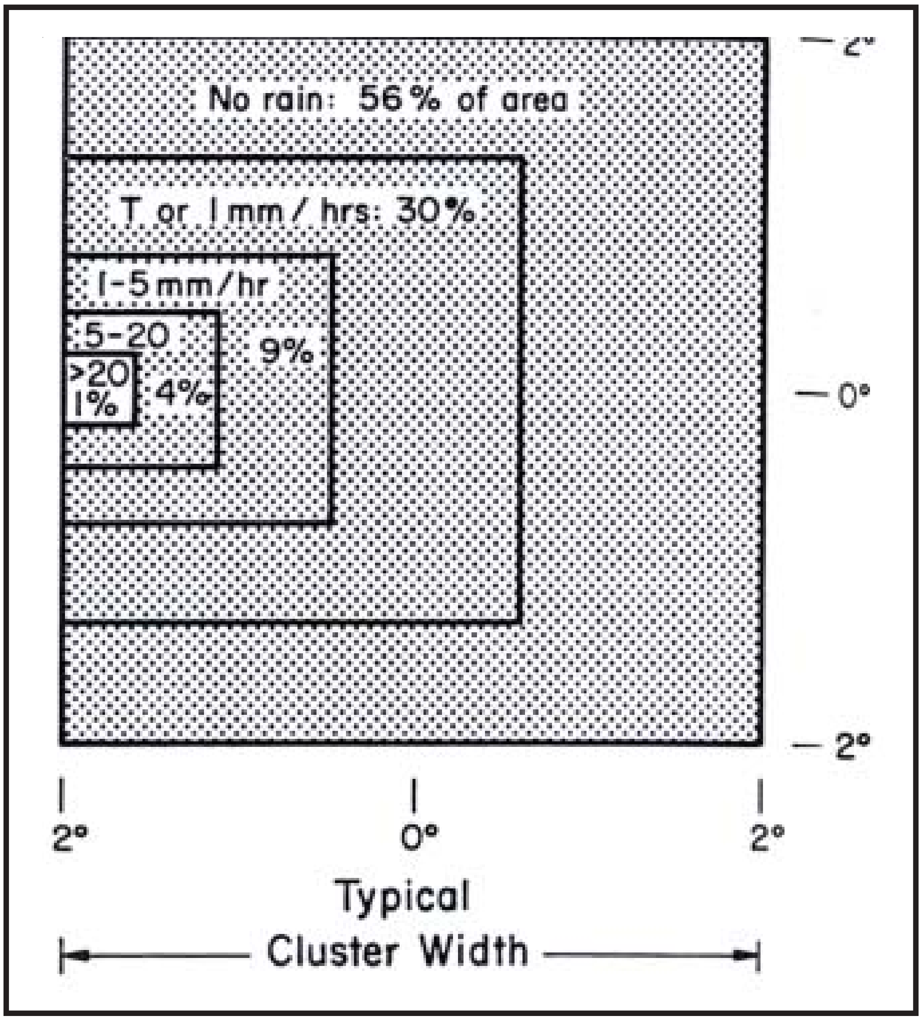

Figure 2-54. Area Distribution of Rainfall Intensity within the Typical Western Pacific Cloud Cluster. Shows the percentage of the horizontal cluster area occupied by various rainfall intensities. It does not mean that all cloud cluster rainfall is concentrated in a small quadrant at the leading edge of the cluster, but this depiction is considered typical of the cluster rainfall pattern. At times the rain may be more randomly distributed. (From Ruprecht and Gray, 1976).

from the equator. MCCs produce heavy rain and hail. About 40 percent of the rainfall associated with tropical MCCs is from stratiform clouds. The hail in the tropical MCCs is softer than that formed in MCCs outside the tropical areas. Figure 2-55 shows a model of a typical MCC.

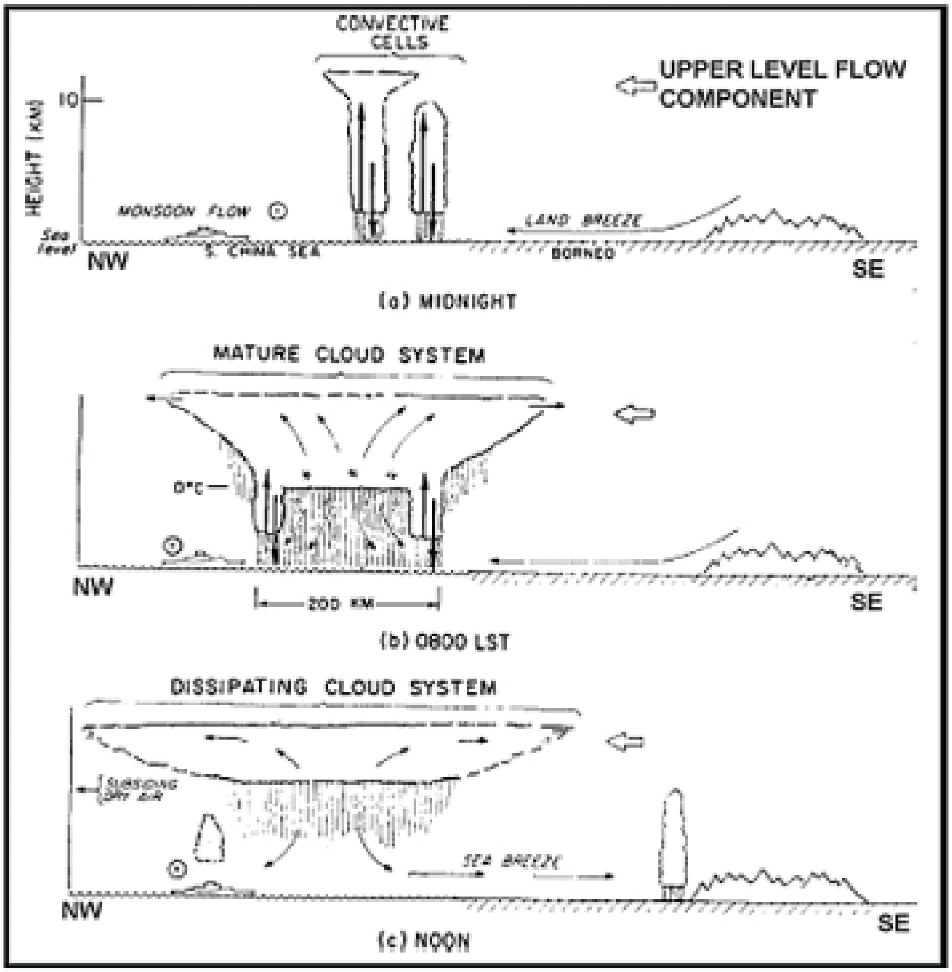

Figure 2-55. Model of the Life-Cycle of a Diurnally Generated MCC off Borneo. (A) The MCC begins as a group of isolated convective cells when the land breeze begins to converge with the low-level monsoon flow (depicted by circumscribed dot--flow out of page) at midnight. By 0800L (B), the precipitation evolves into a continuous mesoscale rain area consisting of a combination of deep cells and stratiform rain falling from mid-to-upper level anvil cloud, whose base is near the 0C level. By noon (C), heating over Borneo produces a sea breeze, and the opportunity for air from the land to converge with either the downdraft or the monsoonal flow is cut off. This results in the cessation of low-level convergence and cell formation. The stratiform precipitation and anvil cloud then slowly dies out. The upper-level cloud, however, continues to expand horizontally. The sea breeze also induces convective cell formation along the coast line. New cell formation could have continued on the northwest side of the cloud system where the monsoonal flow was still meeting downdraft air. However, as the upper-level flow carries the anvil cloud and its associated precipitation further out to sea, the cloud system probably encountered drier, generally subsiding monsoon air in the mid-troposphere. Any new convective clouds forming in response to the low-level convergence would be small and suppressed. By late evening, the upper-level clouds generally ceases precipitating and nearly evaporates. (From Houze, etal, 1981).

The average life span of the typical MCC is 12-14 hours. Formation usually occurs around 2200L; dissipation occurs between 0800 and 1000L. MCCs reach their maximum intensity between 2300 and 0500L. Some MCCs, especially those that form over water away from land masses, can last 2-3 days under the right conditions. They do, however, undergo a diurnal fluctuation in their convection. More than 80 percent of MCCs form over or near a land area. The trigger for many is the interaction of convective cells or cloud clusters with a land breeze or a sea breeze front; others are orographically induced. Some are formed by the interaction of the convective cells with the NETWC or the northeast/southwest monsoons. For those MCCs that form over the open water, convergence of the low-level wind flow is usually the trigger. MCCs move to the right (left in the Southern Hemisphere) of the climatological mean 700-500 mb wind flow. Some MCCs that form over the open water, can intensify and evolve into tropical cyclones. Others can grow to dimensions similar to a tropical cyclone. When they do, they can interact with a tropical cyclone in a manner similar to that of another tropical cyclone, or induce a short-term change in the cyclone's path.

Diurnal Wind Circulations.

Land/Sea Breezes. Differential surface heating generates daytime sea breezes and nighttime land breezes along most coasts of larger islands in the western Pacific basin. Small islands do not generally have sufficient land to generate a land/sea breeze environment. With the monsoon wind reversal, land/sea breeze effects change dramatically from season to season. The breezes are most pronounced during the transition period between the southwest and northeast monsoons, when surface insolation is strongest and synoptic-scale wind circulation is weakest. The marine boundary layer, where the land/sea breeze circulation occurs, rarely extends above 3,000 feet AGL or beyond 19 miles (30 km) inland unless modified by synoptic flow. Two types of land/sea breezes ("common" and "frontal") are described below.

- "Common" land/sea breezes affect many coastal areas of the larger islands of the western Pacific basin. Figure 2-56 illustrates the common land/sea breeze circulation along a uniform coastline under calm conditions with no topographic influences. Onshore (A) and offshore (B) flow intensifies in proportion to the daily heat exchanges between land and water. Common land/sea breezes normally reverse near dawn and dusk; the onshore sea breeze circulation occurs during the day and the offshore land breeze forms at night. The sea breeze is at its maximum strength during the afternoon.

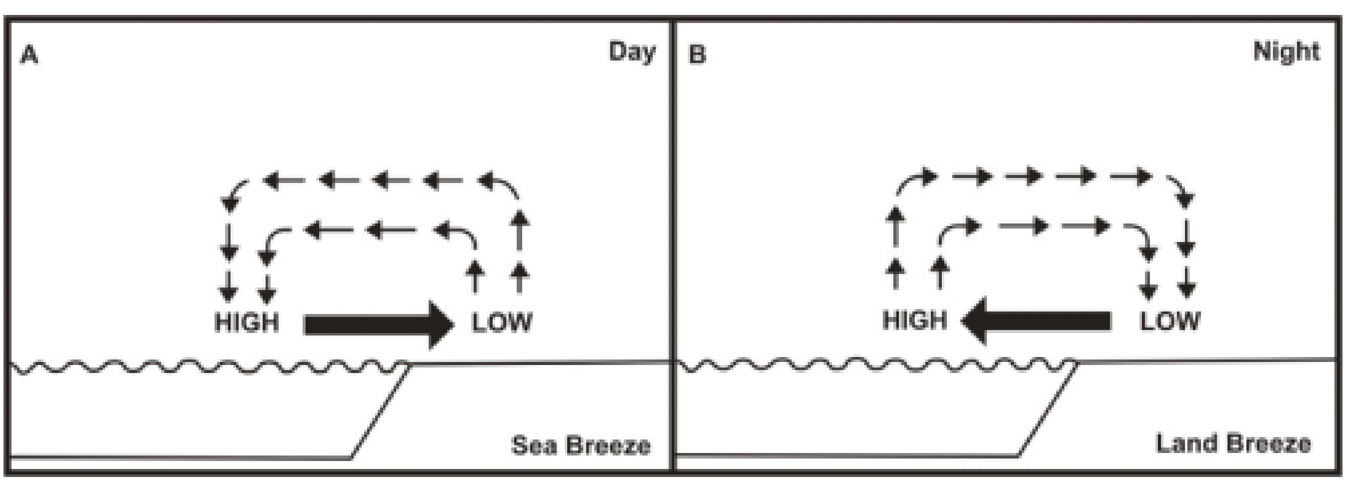

Figure 2-56. The "Common" Sea (A) and Land (B) Breezes. Thick arrow depicts the surface flow.

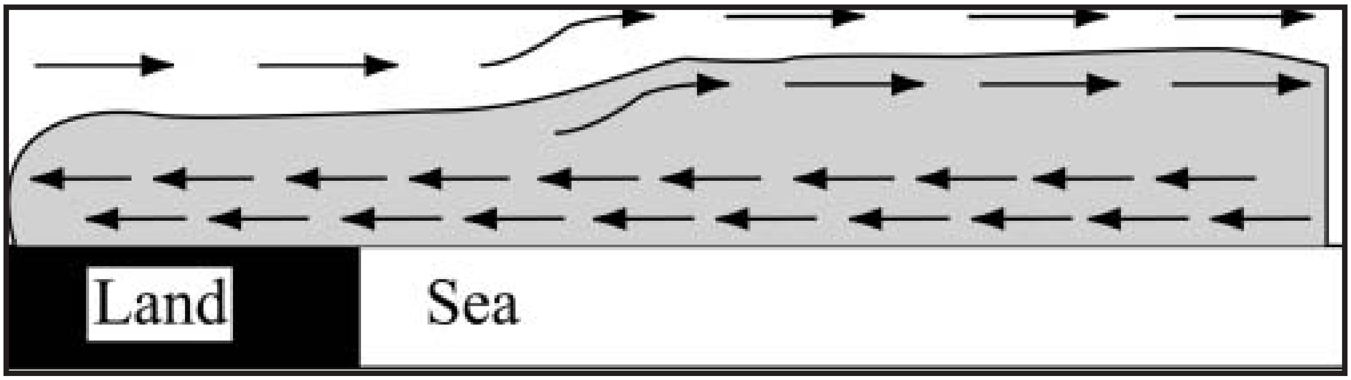

Figure 2-57. Frontal land/Sea Breezes. Boundaries such as these are often associated with low level jets (heavy arrows). Gradient flow is depicted by the lighter arrows.

• "Frontal" land/sea breezes occur when a breeze circulation forms in combination with strong flow perpendicular to the coast. In these cases, a boundary forms such as that shown in Figure 2-57. This is often linked to low-level jets, shown as heavy arrows in the figure. Onshore gradient flow enhances the sea breeze; offshore gradient flow strengthens the land breeze and weakens the sea breeze. With offshore flow, the time of the wind reversal is delayed by 1-4 hours as gradient flow prevents the sea breeze boundary layer, or "front," from moving ashore. Under these conditions, the strongest sea breezes may occur near midnight, contrary to the norm.

High terrain near the coastline modifies the land/sea breeze in several ways. Orographic lifting produces sea breeze-stratiform/cumuliform cloudiness over the higher terrain, while nocturnal downslope winds from the mountains accelerate the land breeze. Figure 2-58 shows how the land/sea breeze circulation is affected by onshore gradient winds and coastal topography. Onshore gradient flow accelerates orographic lifting by day and enhances cloudiness over ridge tops. It also produces localized cloudiness over the open water during the early morning because of convergence with the land breeze and downslope flow from the high terrain. Coastal configuration also has an effect on land/sea breezes. Coastlines perpendicular to landward synoptic flow maximize sea breeze penetration, while coastlines parallel to the flow minimize it.

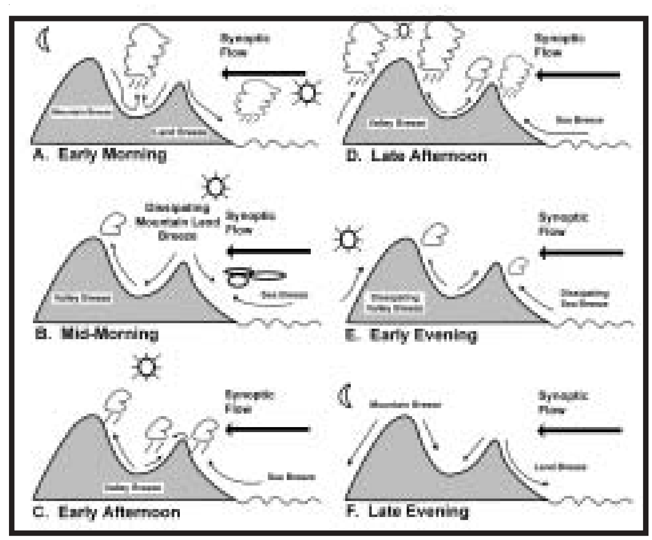

Figure 2-58. Land/Sea Breezes with Onshore Gradient Flow. Thick arrow depicts the surface flow.

Land/Lake Breezes. Variations of land/sea breeze circulation are caused by differential heating over large lakes. This circulation occurs in the absence of strong synoptic flow and has a vertical depth of 600-1,600 feet AGL. Figure 2-59 shows an idealized land/lake circulation and the cloud patterns associated with it. In the late afternoon (top illustration), a cloud-free lake is surrounded by a ring of convection of some 12-24 miles (20-40 km). By early morning, the flow reverses and localized convergence occurs over open water.

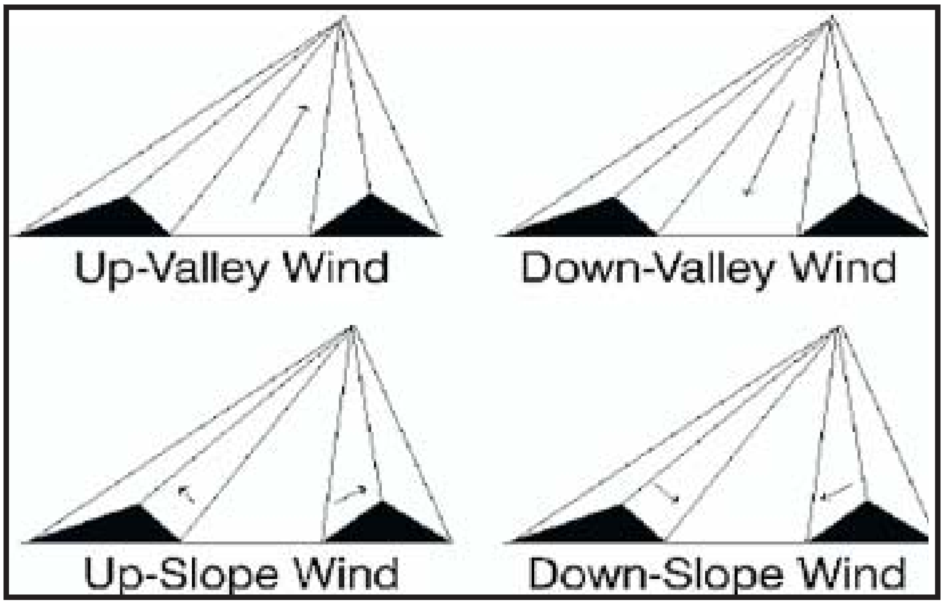

Figure 2-60. Mountain -Valley and Slope Winds. (Whiteman, 1990)**.**

Mountain-Valley and Slope Winds. These winds develop under fair skies with light and variable synoptic flow. Mountain-valley winds, like land/sea breezes, dominate the weather close to the equator, especially when the monsoon is weak. A strong monsoon diminishes these effects, particularly away from the equator. Nocturnal mountain winds that flow toward the sea are capable of initiating thunderstorm activity, particularly over western Borneo.

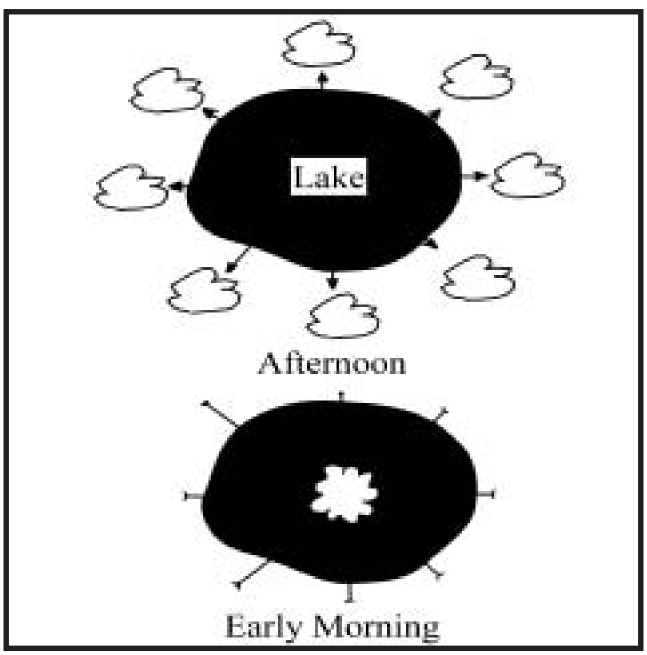

Figure 2-59. Idealized Land/Lake Breezes with Cloud Patterns.

The two types of terrain-induced winds, valley winds and slope winds, are shown in Figure 2-60 and discussed below. Valley winds tend to be stronger than slope winds and can override their influence.

- Mountain/valley winds develop in response to temperature gradients between mountain valleys and nearby mountains. The air on the upper slopes of the mountains receive sunlight before the valley floor and consequently heats faster. The resulting upslope winds flow during the day and are strongest in the mornings and weaker by afternoon when the temperature is equalized between the mountain slopes and valley floor. The flow reverses at night when the mountain slopes cool faster and cooler air slides downhill. The mesoscale mountain-valley circulation has a maximum vertical extent of 6,500 feet AGL. It is determined by valley depth and width, the strength of prevailing winds in the mid-troposphere (stronger winds produce a shallower circulation), and the breadth of microscale slope winds. These winds can spread their influence into nearby plains areas. Upslope winds during the day pull air into the valleys from the plains and night downslope winds send air pooling out over the plains from the valley. Winds exiting onto the plains are called valley winds. This is generally known as a valley/plain circulation.

- Slope winds develop in the surface boundary layer (0-500 feet AGL) of mountains and large hills. Mean daytime upslope wind speeds are 6-8 knots; mean nighttime downslope wind speeds are 4-6 knots. Steeper slopes produce higher speeds. Downslope winds are strongest in the winter and upslope winds are strongest during the summer. Upslope winds are also strongest on slopes that face the sun. Winds from a larger mountain can disrupt the winds of smaller mountains.

Figure 2-61 shows the life cycle of a typical mountain-valley and slope wind circulation. Both valley and slope winds are shown in relation to two ridges (BK and BB) oriented NNW-SSE. Dark arrows show flow near the ground; light arrows show flow above the ground.

Mountain Inversions. These develop when cold air builds up along wide valley floors. Cold air descends slopes above the valley at 8-12 knots, but loses momentum when it spreads out over the valley floor. Wind speeds average only 2-4 knots by the time the downslope flows from both slopes converge. The cold air replaces warm, moist, valley air at the surface and produces a thin fog layer near the base of the inversion. First light initiates upslope winds by warming the cold air trapped on the valley floor. Warming of the entire boundary layer begins near 500 feet AGL.

Convergence Zones. Convergence zones between synoptic and diurnal circulations are common, especially

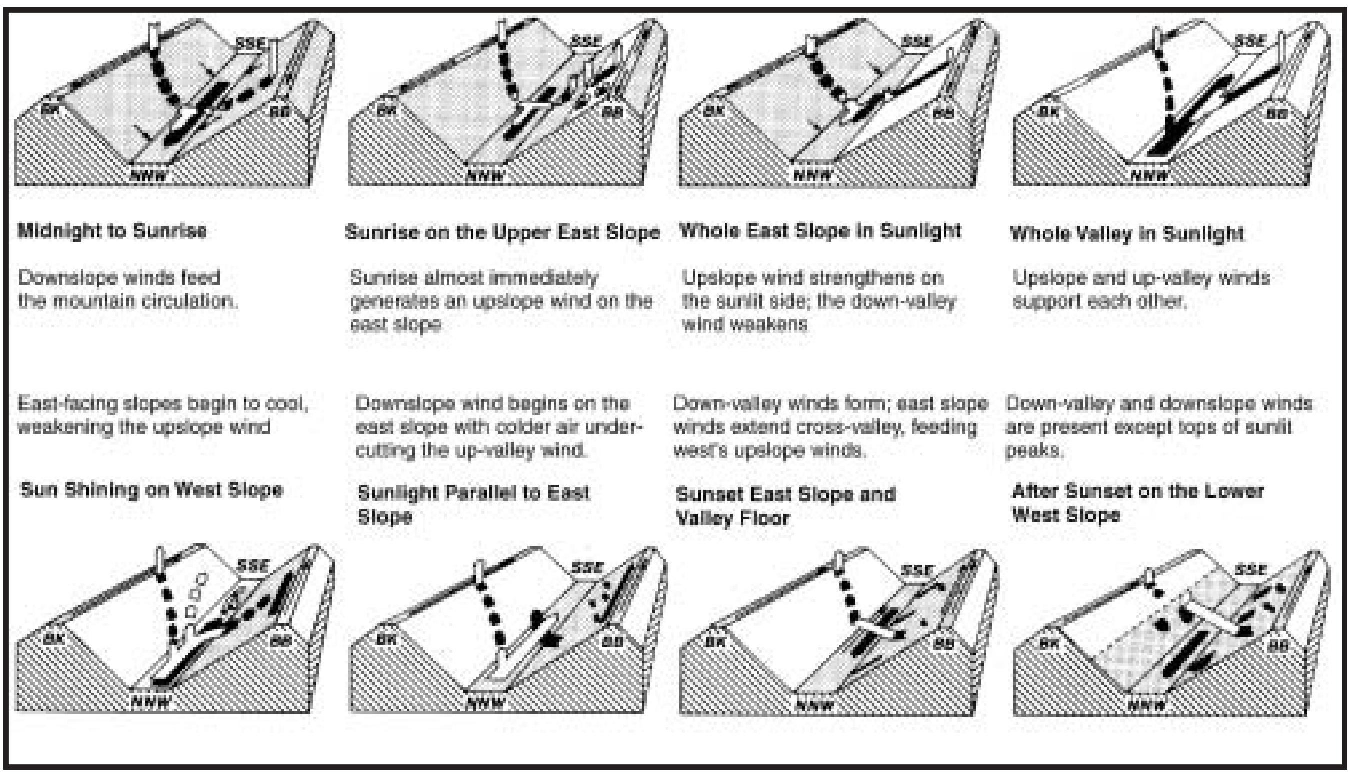

Figure 2-61. Diurnal Variation of Valley and Slope Winds. (Barry, 1991)**.**

in equatorial areas. They are more frequent at night when cool, nocturnal outflow from the mountains reaches the sea during periods of light wind and relatively clear skies. When the cool outflow interacts with the prevailing circulation, the cool air lifts the prevailing airstream and initiates lines of cumulus clouds. These lines often develop into thunderstorms by daybreak, but dissipate during the morning. This type of convergence zone is usually seen off the north coast of New Guinea under light northwesterly flow. It is also seen off the east coast of Borneo.

Another type of convergence zone develops when the low-level circulation interacts with the terrain. One type is produced by the reconvergence of an airstream split by mountains. An example of this occurs in New Guinea. During the southwest monsoon, strong, southeasterly air divides and flows along both sides of the mountains. When the flow rejoins downwind in the vicinity of the Ceram Sea, it forms a wind convergence zone and creates a line of cumulus and cumulonimbus east-west across the Ceram Sea. The clouds reach maximum development and the convergence in the zone reaches greatest intensity shortly before dawn. Surface winds reach 15 knots or more. Similar wind convergence zones are found on the eastern extremity of the north arm of the Celebes with westerly winds and at the north end of the Makassar Strait with a strong southeasterly flow.

Squalls Squalls are strong winds characterized by a sudden onset, a short duration, and a sudden decrease in speed. They are usually associated with an active band of thunderstorms, also known as a squall line, a convergence line, or an isolated severe thunderstorm. Squalls that result from nearly stationary thunderstorms usually occur in the afternoon of early evening. Those over water do not penetrate far inland. Squalls with a convergence line imbedded in the synoptic flow are more pronounced and usually penetrate deeper inland. One type of squall has acquired a local name, the *sumatra*.

Sumatras are nocturnal squall lines that form in the Strait of Malacca during the southwest monsoon. They develop most frequently between 2100 and 0400L over the water between Port Swettenham (3° N, 101° E) and Singapore. Sumatras are caused by the convergence of east-moving land breezes from Sumatra with west-moving land breezes from the Malay peninsula. The southwest monsoon enhances this convergence by reinforcing the land breeze from Sumatra and moving the thunderstorms as far as 30 miles (50 km) inland on the Malay Peninsula. The lines of thunderstorms arrive on the Malayan coast late at night or early in the morning as a band of cumulus and cumulonimbus 125-185 miles (200-300 km) long. Sumatras are oriented northwest-southeast and move northeast, sometimes as fast as 40-50 knots. They can cause heavy rainfall for 1-2 hours and winds of up to 40 knots. Rainfall can exceed 80 mm in one night. Sumatras cause a sudden temperature drop that lasts for several hours. Sumatras are most common in July, when 6-8 normally occur.

Local Wind Systems.

Mountain Waves. Mountain waves can develop when air is forced over the windward side of a ridge. Criteria for mountain wave formation include sustained winds of at least 15-25 knots, winds that increase with height, and flow oriented within 30 degrees of perpendicular to the ridge. The wavelength and amplitude of mountain waves depend on the wind speed and the lapse rate above the ridge. Light winds follow the contour of the ridge, with little wave formation. Stronger winds displace air above the stable inversion layer and form waves. This upward displacement of air can reach the tropopause. Downstream, the wave propagates an average distance of 50 times the ridge height. Rotor clouds form when there is a core of strong winds moving over the ridge, but the elevation of the core does not exceed 1.5 times the ridge height. Rotor clouds produce the strongest turbulence. Figure 2-62 shows a fully developed lee wave system.

Foehn Winds. Foehns are hot, dry winds that occur as air that has been forced over mountain tops descends the leeward slopes adiabatically. Foehn winds are prevalent in sections of Sumatra, Java, Borneo, and Celebes. They also occur on a smaller scale elsewhere in the western Pacific basin. Sometimes these winds are so hot and dry, crops in the fields on the leeward sides of the mountains are severely withered or completely destroyed.

Jet-Effect Winds. Jet or funneling winds occur on the downward sides of narrow mountain passes under strong gradient conditions induced by wind funneling. These winds are almost always "supergradient" with speeds as much as 35-45 knots higher than gradient winds. The long, narrow valleys and mountain gaps in Indonesia and East Malaysia are prime locations. These winds occur most during the northeast monsoon.

Topography. Topography is an extremely important factor. Because of the high temperatures, moisture content and marked instability of the air, little lift is needed to produce cloudiness and rainfall. Thus the form, orientation, height and extent of the topographic features become important. Monsoonal flow against mountain ridges produces continuous cloud banks on windward slopes and over peaks. The diurnal wind cycle generates the same effect. Air brought in by sea breezes produces cloud banks, often towering cumulonimbus on the slope of the mountains. On the leeward side of the mountains, the downslope airflow produces a clearing tendency. The terrain also greatly influences the local wind and rainfall patterns.

The topography varies considerably throughout the basin. Many small islands are low in elevation so orographic influences on rainfall and cloudiness are practically negligible. On the other hand, the larger islands are more rugged and mountainous.

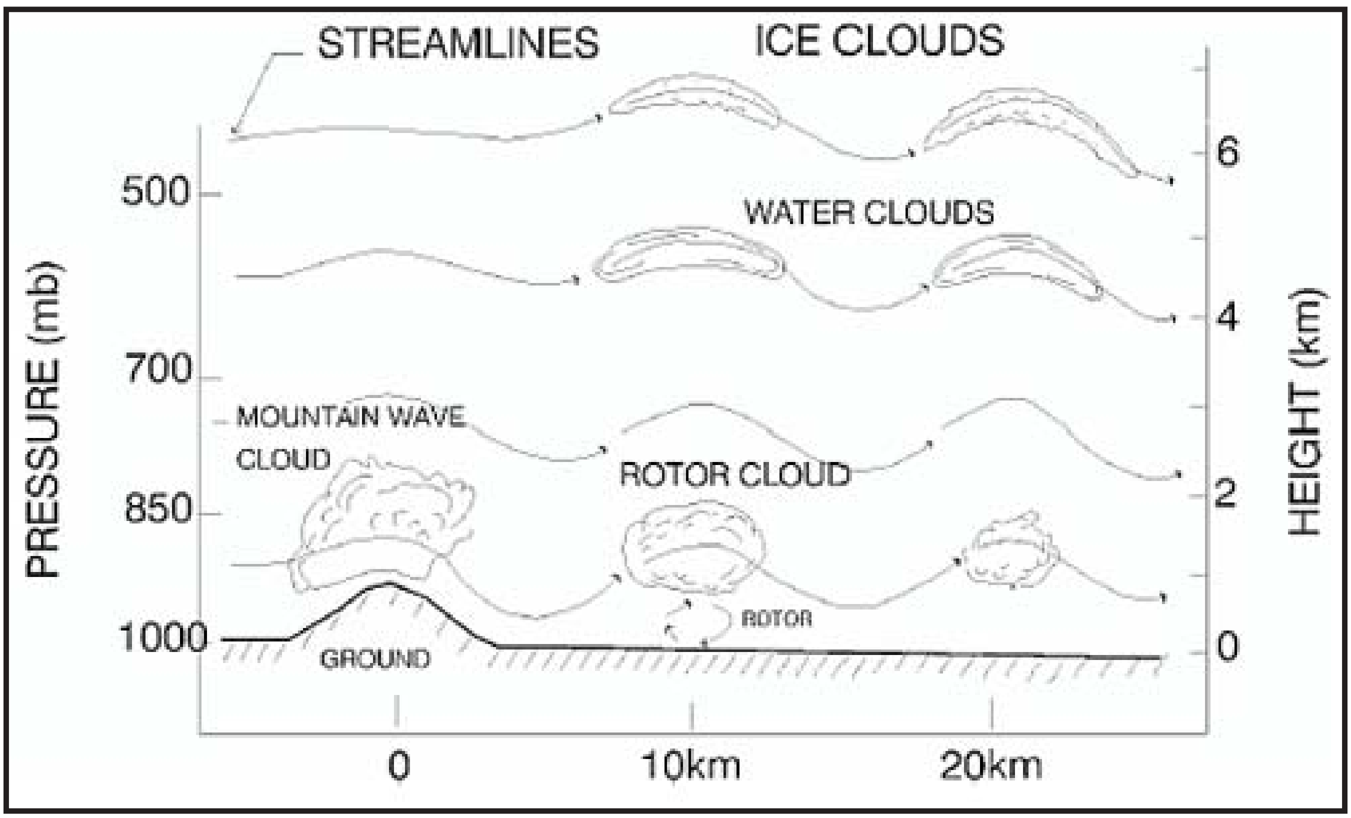

Figure 2-62. Fully Developed Lee Wave System. (Wallace and Hobbs, 1977)**.**

Flooding. This region is subject to some of the heaviest rainfall in the Pacific, both on a long- and a short-term basis. Tropical thunderstorms and tropical cyclones release an incredible amount of rain in a very short time. Some locations in New Guinea have recorded over 19.6 inches (500 mm) of rain in a single day. Other locations have recorded over 30 inches (750 mm) in a single month. Flash flooding occurs frequently in the valleys and the lowlands when the rivers and streams are unable to cope with the massive amount of water.

Drought. The rapid evaporation and transpiration that occur in parts of the basin lead to drought if monthly rainfall totals fail to compensate for the moisture loss. Droughts can develop quickly even when the previous month's rainfall total was above normal. This is particularly true in the southern tier of islands of Indonesia. Droughts are common from May to October in the Lesser Sunda Islands. During this period, the dry, southerly wind flow offers conditions favorable to rapid evaporation and transpiration. Monthly rainfall totals of less than 3 inches (75 mm) would not make up for the moisture loss.

Volcanoes. Many active volcanoes exist within the western Pacific basin (Figure 2-63). Although volcanic eruptions are infrequent, they do pose serious hazards to aviation and ground activities. Within ten minutes of an explosive eruption, tons of very small rock fragments, known as volcanic ash, and corrosive gases are thrust into the upper troposphere and lower stratosphere. Shock waves from the volcano explosion, along with the ensuing lava flow, can cause massive damage to ground structures near the volcano.

Volcanic ash in the atmosphere poses a serious danger to aircraft in flight. The drifting ash clouds are carried away from the region by the mid- and upper-level winds.

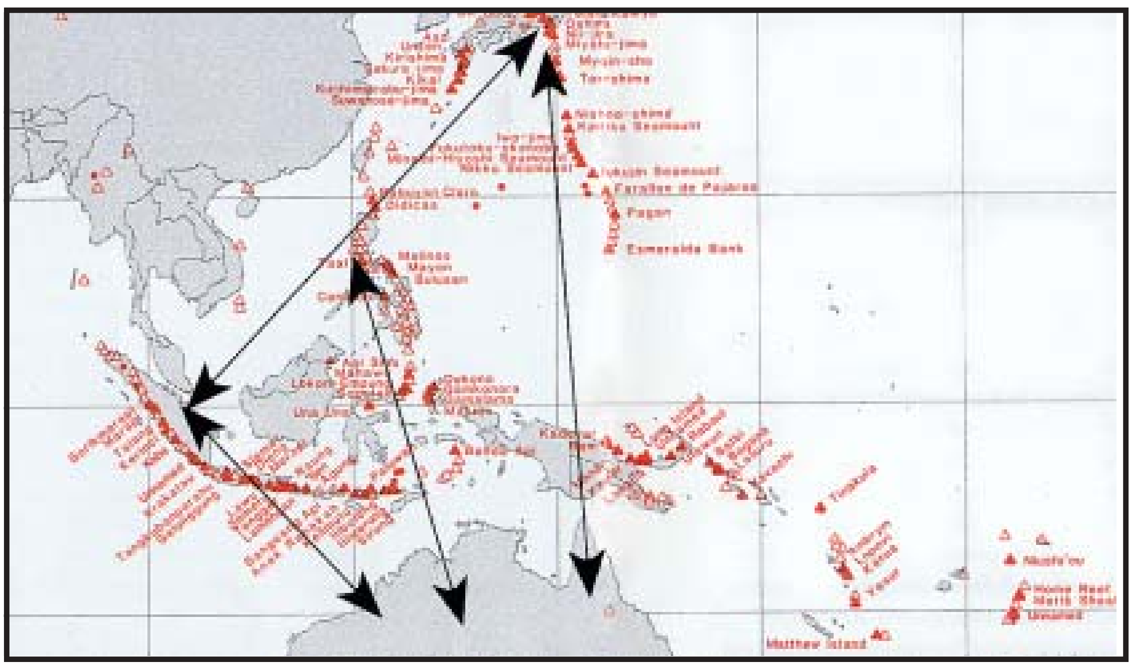

Figure 2-63. Map of Historically Active Volcanoes and Principal Air Routes. The clear triangles indicate the position of volcanoes which erupted during the last 10,000 years. The solid triangles indicate volcanoes which erupted between 1975 and 1989. The solid circles indicate thermal fields and possible, but uncertain, eruptions. The solid lines with the arrows indicated principal air routes over the region. (From Casadevall, 1995).

Ash clouds that make it into the stratosphere may be carried by the jet streams for thousands of miles (see Figure 2-64). Aircraft radar cannot detect the presence of ash clouds--a limitation on the sensitivity and power/ aperture of radar. Visual identification of the ash cloud from aircraft is also difficult.

The fine, airborne ash can cause a wide variety of damage to aircraft that encounter it in-flight. The abrasive ash can damage engines, landing lights, control surfaces, windows and windshields. The windshield could become opaque. Jet engines ingesting the ash may cease to operate, an occurrence that affected two 747 passenger jets encountering the ash cloud from eruptions of the Galunggung, Indonesia volcano. In both cases, the jets lost power in all engines. After a 25,000 -foot powerless descent, the pilots were able to restart the engines and make an emergency landing at Jakarta, Indonesia.

Earthquakes. These events affect every country and many of the islands of the western Pacific basin, They occur frequently in New Guinea, Indonesia and the Philippines, but less often on Borneo and in the Mariana Islands. The duration of the earthquakes last from a few seconds to a few minutes. The damage from an earthquake is dependent upon its duration, the texture of the ground, and building construction. Further compounding the damage problem are the landslides triggered by the earthquakes in the mountainous regions.

Tsunami. These waves are generated by a physical disturbance, such as an earthquake or a volcano eruption. The western Pacific basin is affected by them due to its intense volcano and earthquake activity. The coastlines of all of the countries and the islands in the region are exposed to them. The classical description of a tsunami follows. The water along the coastline first withdraws from the shore. The water then returns as a breaker that may reach heights of 40 fee (12 meters) or more. The wave then carries away almost everything in its path. Some tsunamis may travel a mile or more inland before returning to the sea.

An actual tsunami may not follow the classic pattern. Some of them are preceded by the withdrawal of the water, others arise from the sea with little or no warning. Nor does the tsunami always take the form of a curling breaker. It may manifest itself as a sudden upsurge of the sea. A train of tsunamis usually has such great

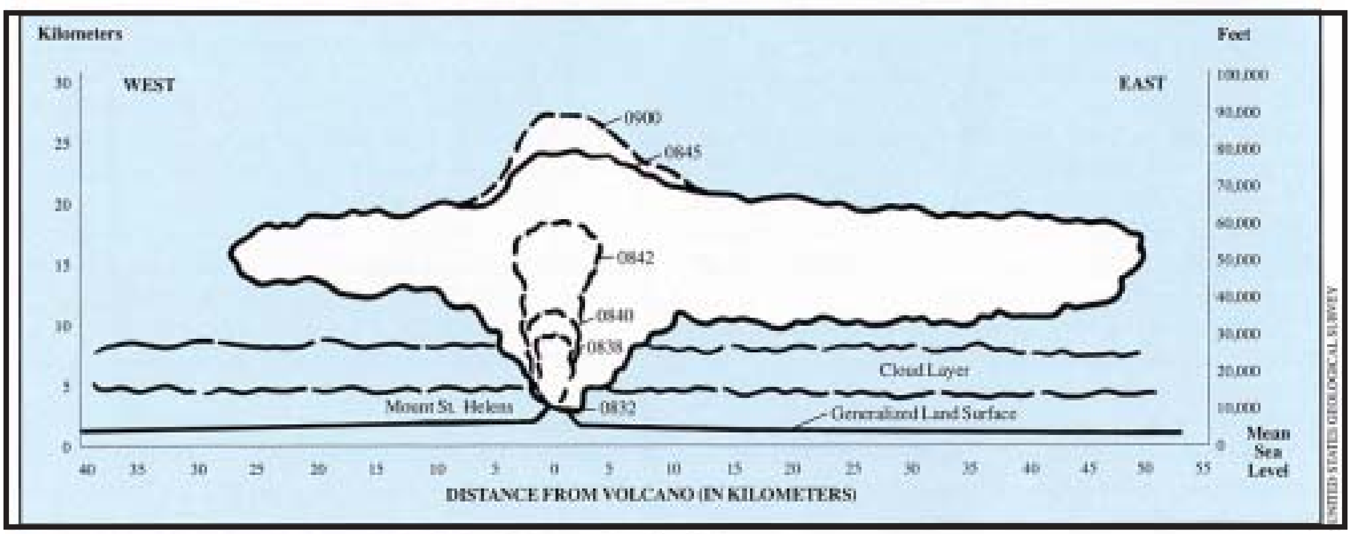

Figure 2-64. Profile of a Volcanic Explosion. Depicts the early vertical growth and lateral expansion of the ash plume from the 18 May 1980 explosive eruption of Mount St. Helens. Within 30 minutes of the eruption, the ash cloud topped 80,000 feet and the cloud spread laterally through the airmass at speeds averaging 95 knots. (From Steenblik, 1990)**.**

wavelengths that the waves may not be noticed by the ships they pass under. But as the waves approach land, and shallow water, they rise and take on the familiar form. The exact characteristic of a tsunami depends on several factors, including the shape of the seabed and shoreline. A tsunami could be funneled into a narrow inlet, increasing the forward speed of the water, greatly increasing its destructive power.

In the open oceans, the waves may travel at several hundred knots, but slow down 40 or 50 knots as it approaches land. The waves then crowd together and may be spaced about a few thousand feet apart. This compressed spacing means that several towering waves may hit the shore in rapid succession, with devastating impact.

Wet Bulb Globe Temperature (WBGT) Heat Stress Index.

The Wet Bulb Globe Temperature (WBGT) heat stress index provides values that can be used to calculate the effects of heat stress on individuals. WBGT is computed using the formula:

$$WBGT = 0.7WB + 0.2BG + 0.1DB,$$

where: WB = wet-bulb temperature
BG = Vernon black-globe temperature
DB = dry-bulb temperature

A complete description of the WBGT heat stress index and the apparatus used to derive it is given in Appendix A of TB MED 507, Prevention, Treatment and Control of Heat Injury, July 1980, published by the Army, Navy and Air Force. The physical activity guidelines shown in Figure 2-65 are based on those used by the three services. Note that the wear of body armor or NBC gear adds 6°C to the WBGT, and activity should be adjusted accordingly. See Figure 2-65 for WBGT values in the western Pacific.

Table 2-2. WBGT Heat Stress Index Activity Guide.

WBGT (° C)	Water Requirement	Work/rest Interval	Activity Restrictions
32-up	2 quarts/hour	20/40	Suspend all strenuous exercise.
31-32	1.5-2 quarts/hour	30/30	No heavy exercise for troops with less than 12 weeks hot weather training.
29-31	1-1.5 quarts/hour	45/15	No heavy exercise for unacclimated troops, no classes in sun, continuous moderate training 3rd week.
28-29	.5-1 quart/hour	50/10	Use discretion in planning heavy exercize for unacclimated personnel.
24-28	.5 quart/hour	50/10	Caution: Extremely intense exertion may cause heat injury.

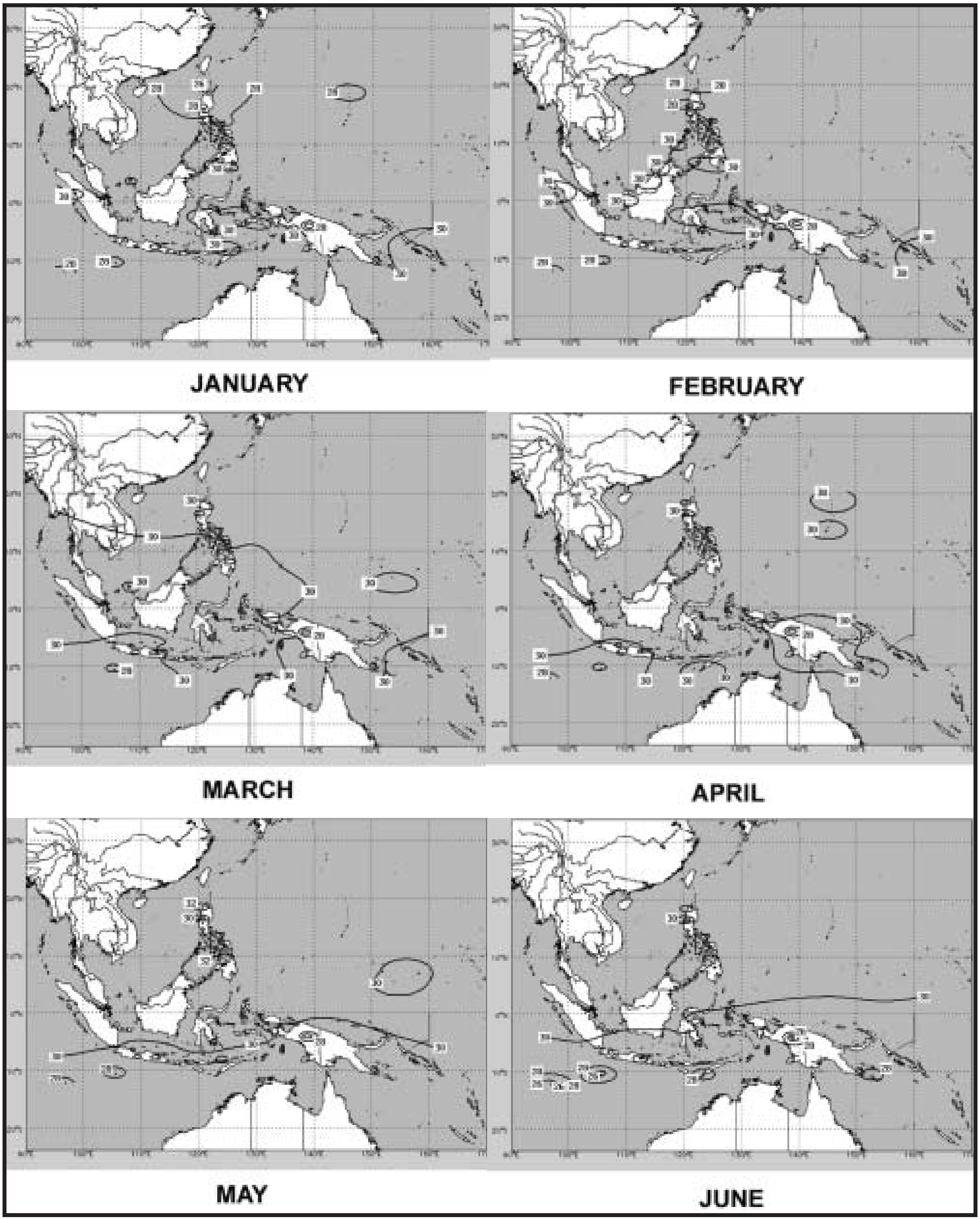

Figure 2-65a. Mean Maximum Wet Bulb Globe Temperature Index (January - June).

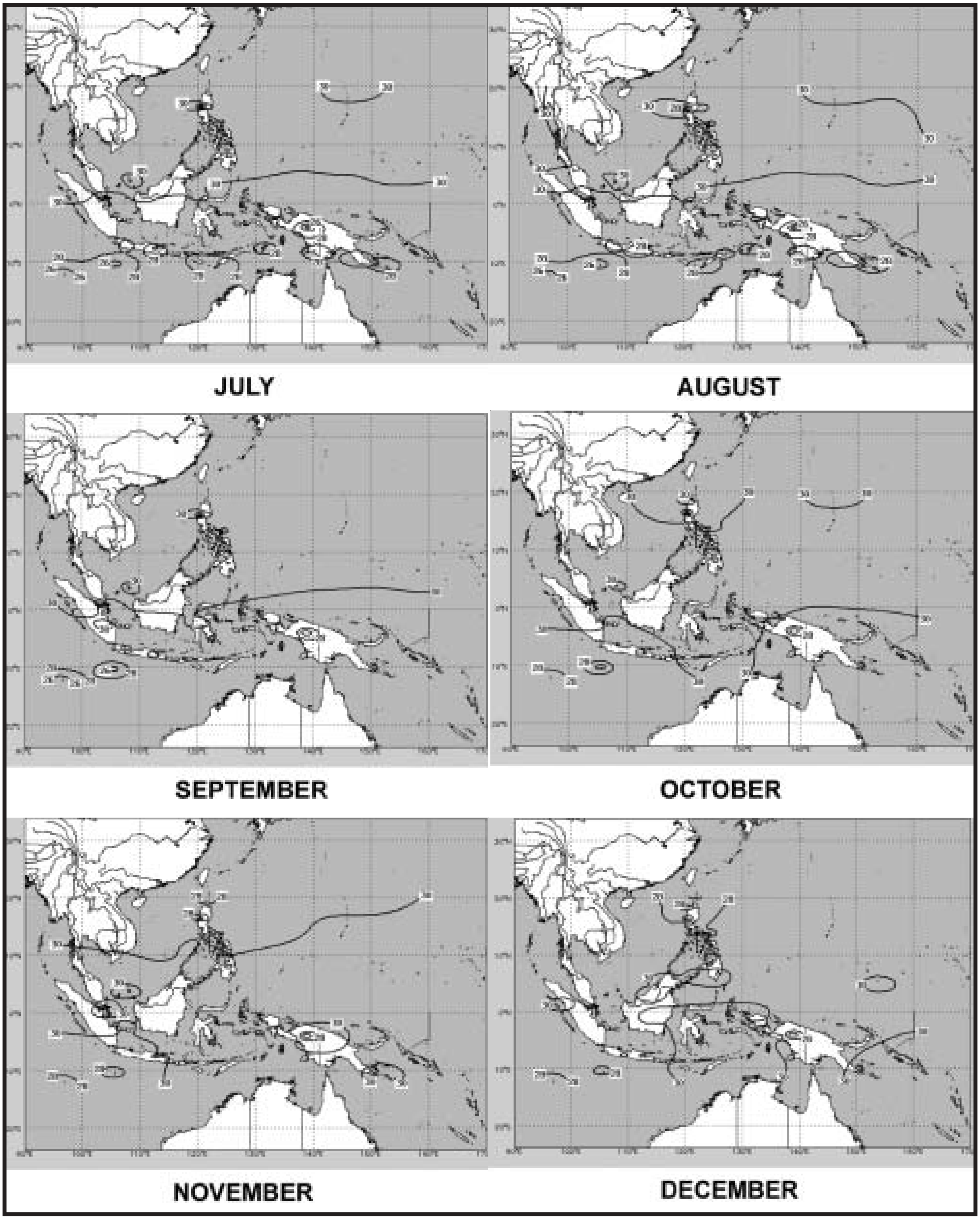

Figure 2-65b. Mean Maximum Wet Bulb Globe Temperature Index (July - December).

Chapter 3

SUMATRA, JAVA AND THE LESSER SUNDA ISLANDS

This chapter describes the geography, major climatic controls, special climatic features, and seasonal weather for Sumatra, Java and the Lesser Sunda islands. The Lesser Sundas include all the islands between Bali and Timor along the chain of islands south of Borneo.

Figure 3-1. Sumatra, Java and the Lesser Sunda Islands. The figure shows the location of Sumatra, Java and the Lesser Sunda Islands in relation to other countries in the western Pacific region.

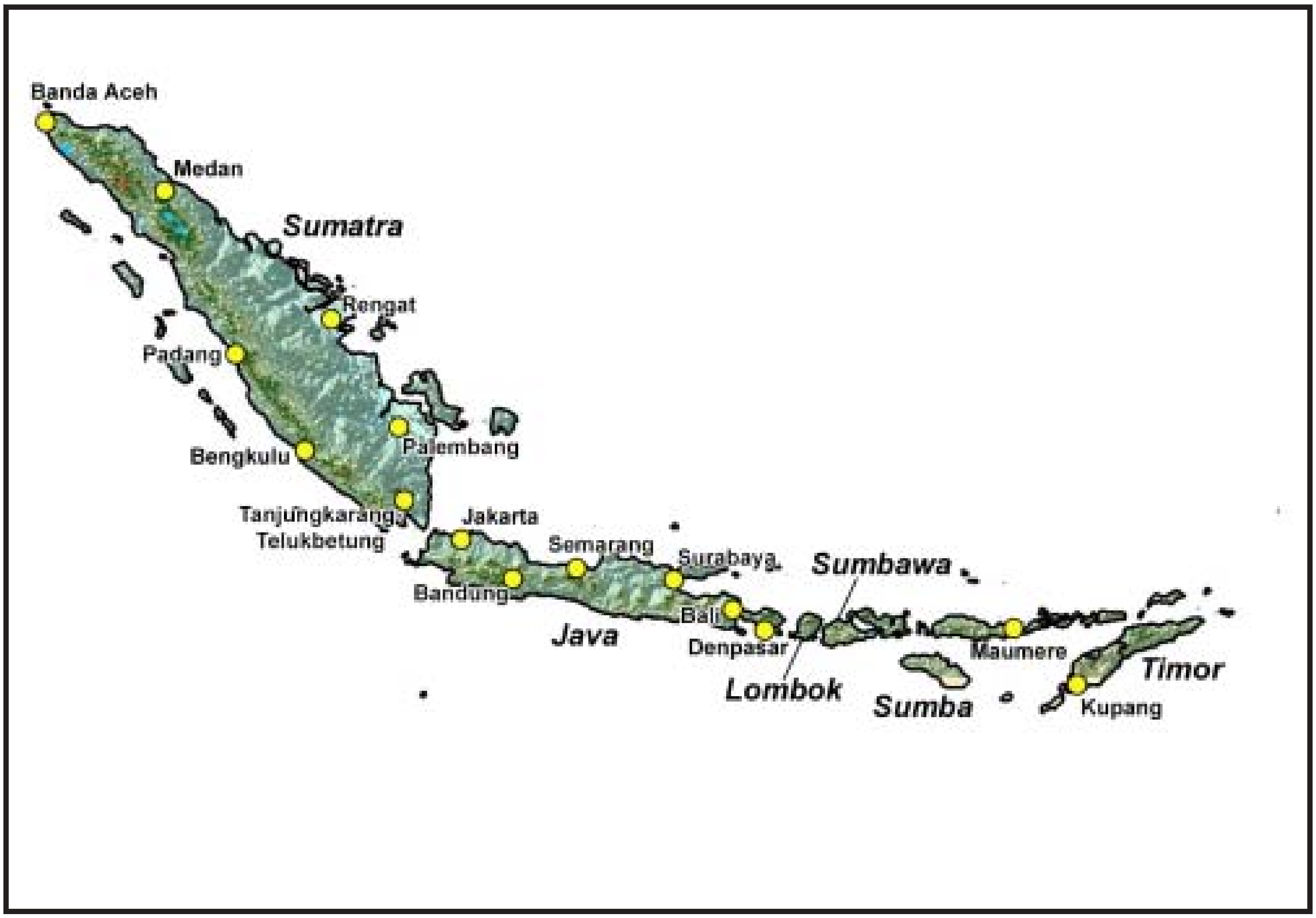

Figure 3-2. Topography of Sumatra, Java and the Lessor Sundas.

TOPOGRAPHY.

Sumatra and Java are two of the Greater Sunda Islands and lie south of the Malay Peninsula. The remaining islands, south of Borneo, make up the Lesser Sunda Islands. Sumatra, as the largest of the islands, will be discussed separately, then Java and the remaining islands will be discussed. See Figure 3-2 for the map of Sumatra, Java, and the Lessor Sundas.

Sumatra.

The West End. The Atjeh highland covers the southern two-thirds of the west end of the island. It is described in more detail in the section on mountains. North of that, the terrain slopes gradually down toward the north coast. In the distance between 40 miles (65 km) inland and the coast, the elevation lowers from 500 feet (150 meters) to less than 100 feet (30 meters). In the near coastal areas, the land is close to sea level. Wide deltas, with constantly shifting bars and snags, choke the mouths of many rivers on the north coast.

The Central Hills and Plains. North of the mountains, the terrain descends into highland areas first, then gradually into lowlands that begin around 3° N 97° E. These central hills and plains extend southeastward the length of Sumatra. They are heavily dissected with rivers and streams that drain to the north coast from the mountains.

The Eastern Alluvial Lowland. This is a 40-60 mile (65-95 km) swath of land along the north coast from 3° N 98° E all the way to the east end of the island where it wraps around the eastern tip. The many rivers, abundant rains, and warm temperatures foster dense tropical forests that give way to plantations, rice paddies, and eventually, mangrove swamps on the coasts.

The Southern Coast. The southern coast is a very narrow strip between the mountains and the sea. The mountains rise precipitously so rivers are numerous, short and fast. There are very few mangrove thickets on this side of the island. The beaches are mainly coral sands with reefs close to shore.

Mountains. On the west end of the island, the Atjeh highlands are the west end of the volcanic mountains that are the spine of Sumatra from end to end. Elevations rise from northwest to southeast along the highland. In the western half, they average 5,000-7,000 feet (1,500-2,100 meters) with a few peaks above 9,000 feet (2,700 meters). The eastern half elevations rise to 6,000-9,000 feet (1,800 to 2,700 meters) with a few peaks over 10,000 feet (3,000 meters). The terrain slopes down toward the east along the ridge line to Danau Toba (Lake Toba) at 2° 40' N 98° 45' E. Beyond that, the ridge continues to slope gradually lower to 4,000-6,000 feet (1,200-1,800 meters) with some volcanic peaks of 8,000-9000 feet (2,400-2,700 meters).

The Atjeh highlands end around 0° 10' N 100°E where the Barisan Mountains begin. The Barisans rise quickly from the lower ridges of the southern highlands. This spine of mountains is approximately 60-90 miles wide just about its whole length. Average elevations are 7,000-10,000 feet (2,100-3,000 meters) with several peaks over 11,000 feet (3,400 meters). The mountains are volcanic in origin. The mountains continue to the eastern tip of the island where they split into two ridges, one that trails off the narrow peninsula on the southeastern tip of the island and the other, slightly north of that, on the other side of Semanko Bay. The Atjeh highlands and Barisan Mountains are sometimes collectively called Bukit Barisan.

There are many tiny islands around Sumatra; many are no more than unnamed coral atolls. At the western tip of Sumatra, a tiny island group is just off the coast. Average elevations in the islands are close to sea level, but there are 400 to 520-foot (120-160- meter) hills on some. There are many islands in the Strait of Malacca. Of the larger ones, the farthest west island is Rupat. From there to the east end of Sumatra, the islands are Bengkalis, Padang, Tebingtinggi, Rangsang, Mendol, Kundur, the Riau Archipelago, the Lingga Archipelago, Bangka, and Belitung. These islands have low plains between sea level and 250 feet (75 meters) in elevation; many have 1,200 to 3,800-foot (350-1,120-meter) hills. The eastern islands have higher hills than those in the west. The islands south of Sumatra are in a line that extends along its coast nearly from end to end. The farthest west of the larger ones is Simeuluë. In a progression southeastward from there, are the Banjak Islands, Nias, the Batu Islands, the Metawasi Islands, and Enggano. The average elevation of these islands is 500-1,200 feet (150-360 meters). Many of the islands have small mountains on them. Krakatau is a small island at the southern mouth of Sunda Strait in a small scattering of islands between Sumatra and Java.

Lakes. Many Sumatran lakes are in volcanic craters. The major lakes from west to east are: Danau (Lake) Tawar (4°37' N, 96°57' E), Danau Toba (2°30' N, 98°45' E), Danau Manindjau (0°20' S, 100°10'E), Danau Singkarak (0°35' S, 100°32' E), Danau Keniti (2°10'S, 101°28' E), and Danau Ranau (4°55'S, 103°55'E). Between these larger lakes, many small ones dot both the mountain range and the drainage plains between the mountains and the north coast. At an elevation of 2,985 feet (910 meters), Danau Toba is the largest lake on Sumatra at 45 miles (72 km) long.

Rivers and Drainage. Rivers abound on Sumatra and drain the mountainous spine that extends the length of the island. The rivers on the north side of the mountains are longer because the mountain ridge is far closer to the southern shore. Sungai Aceh, about 35 miles (55 km) long, descends over 2,000 feet (610 meters) in its course and empties into the Andaman Sea at the western-most tip of Sumatra. Sungai Rokan is approximately 175 miles (280 km) long and empties to the Strait of Malacca at roughly 2° N, 101° E. The Kampar is one of the larger rivers on Sumatra although it is not the longest. It is 200 miles (320 km) long and empties into the Strait of Malacca. Pahang River, in south central Sumatra, is 285 miles (460 km) long. It has many tributaries that are fair-sized rivers in their own right. The Indragiri (alternatively Inderagiri) is a navigable river in central Sumatra. It flows eastward 250 miles (400 km) from the Padang highlands to the north end of the Berhala Strait (between Sumatra and the Lingga Archipelago). Batang Hari is 450 miles (725 km) long and empties into Berhala Strait. The Musi (alternately spelled Moesi) is 325 miles (525 km) long and flows to Bangka Strait. There are hundreds of small rivers. All the rivers listed by name are on the north coast except for Sungai Aceh. The south coast rivers have very short, steep courses.

Java and the Lesser Sunda Islands. Java, one of the Greater Sundas, is volcanic in origin. It lies east of Sumatra. In Sunda Strait, between Sumatra and Java, there are several small islands. The northwest tip of Java has a highland area with two small volcanoes. The mean elevation of the highland is 1,000-2,000 feet (300-600 meters), but the volcanoes are higher. The highland slopes down into the northern plain that stretches all the way to the east coast in a wide band along the north coast of the island. The western tip of Java is a plain that rises steeply to a volcanic highland. The south coast consists of a spine of volcanoes and plains. These plains alternate with volcanoes from 110° E to the eastern tip of the island.

The Lesser Sunda Islands, which lie in a line from east of Java to Timor, are mostly volcanic. A few are large enough to have silty runoff from rivers. Some are little more than volcanic cones encircled by a narrow beach. Others are tiny spits of land with coral reefs around them.

The islands east of Java, in a west-east progression include the following:

- The Karimundjawa Island group is north of the eastern end of Java between 5°40’ and 6° S and 110° and 110°50’ E. The islands are largely coral atolls.

- Bawean is north of the east end of Java at 5°48’ S, 112°38’ E. Surrounded by coral, it is the remains of an ancient volcano.

- The Lesser Sunda islands, which include Madura and a series of small islands (114°20’ E to 116°15’ E on a line along 7° S), Bali, Lombok, Sumbawa, Sumba, Flores, Solor, Adonara, Lomblen, Rusa, Pantar, Alor, Timor, Roti (southwest of Timor), Ilha De Arauro, Liran, Wetar, Njata, Romang, Tellang and Maopora.

- North of 8° S, the Leti Islands and Kisar are considered parts of the Molucca group, but they are very close to Timor, the easternmost Lesser Sunda Island.

- Many tiny, unnamed islands and coral atolls exist through the chain of islands.

*Mountains***.** Mountains on all the islands from Java to the Babar Islands are volcanoes. Average elevations on the west end of Java are 7,000-9,900 feet (2,100-3,000 meters), except for those on the northwestern tip. With the exception of two volcanic peaks, the mountains average 1,500-2,000 feet (450-600 meters). The volcanoes are 5,835 feet or 1,779 meters (the northeastern one of the two) and 4,416 feet or 1,346 meters (the southwestern one). On the eastern half of Java, the mountains are higher, 9,000-12,000 plus feet (2,700-3,600 plus meters).

Lakes. The largest lake on Java is man-made. Djatiluhur Reservoir, just west of Purwakarta, is rimmed by high ground (06°35’S, 107°20’E). This sickle-shaped lake wraps two-thirds of the way around a volcano. Rawa Pening (7°16’ S, 110°25’ E) is considerably smaller and appears to be a crater lake.

There are fewer crater lakes on Java than Sumatra, but hundreds of tiny lakes dot the plains. The northern plain, because it slopes so gradually for so much of the way to the Java Sea, has many more river lakes and marshes than the south coastal plain.

Madura does not have large lakes, but it has many small ones in the plains. Danau Batur is the largest lake on Bali. It lies in the northeast corner of the island and three smaller lakes lie at the foot of the north slopes of Bukit Batukau (a mountain at 8° 07' S, 115° 07' E). Lombok has a large crater lake, Gegara Amak, at the peak of its only volcano. None of the other islands have large lakes, but all have small ones in almost every basin, valley, and river bow.

Rivers and Drainage. Only Java has major rivers. The other islands are so small, the rivers are insignificant. All the islands have small rivers. In general, the smallest islands have only streams.

While not comprehensive, the following is a compilation of the larger rivers on Java. They are all navigable for at least a portion of their lengths. On the western tip of the island, Tji (River) Liman flows into Teluk (Bay) Lada in Sunda Strait. Tji Udjung flows to the northwest coast into Teluk Banten (Java Sea). The two rivers flow on either side of the highland at the northwestern tip of Java. Tji Mandiri empties into Palabuhan Ratu (Ratu Sound) on the southwestern coast. Tji Tarum empties Djatiluhur Reservoir northward to a marshy point on the north coast at 107°20' E, 06°35' S.

Tji Tanduj flows through a broad plain into Teluk (Bay) Penangjung-Barat. Its many tributaries come from all the mountains around the plain. Kali (river) Seraju empties into Teluk Penju from tributaries that rise from the highlands. Gunung Merbabu, at 110°25' E, 07°27' S, has many rivers on all but the north flank.

Kali Progo (also spelled Praga) empties directly into the Indian Ocean just west of Jogjakarta. Kali Labang, with mouths on either side of a volcanic point at 110°52' E, 06°35' S, has many tributaries and offshoots (branches) on its twisting route. Bengwan Solo empties into the Java Sea just north of the narrow strait between Java and Madura. The Porong and Brantas are all but indistinguishable as they combine, separate, and rejoin practically from the start. They flow west then north before they finally empty into Selat (Strait) Madura at Surabaja and just north of Bangil. On the eastern end of Java, Kali Bedadun is fed by many tributaries. It flows to the Indian Ocean just north of Barung Island. Gunung Raung has many rivers on all its slopes; some disappear into the lowlands to the north and west, some empty into Bali Strait, and some empty into the Indian ocean.

Major Bodies of Water.

Sumatra. The major sea of Sumatra is the Indian Ocean, which comes to the south shore of the island. The South China Sea comes to the eastern half of the north coast. The Strait of Malacca separates Sumatra from Malaysia and Singapore and lets out into the Andaman Sea to the west and the South China Sea to the east. The eastern end of the island looks out onto the Java Sea and Sunda Strait separates Java from Sumatra.

Java and the Lesser Sundas. The major sea of Java is the Indian Ocean, which comes to the south shore of the island. The Java Sea meets the north coast. Sunda Strait separates Java from Sumatra, and Bali Strait separates Java from Bali. Madura Strait lies between Java and Madura. The Bali Sea laps the north shores of Bali and Lombok. The other Lesser Sundas face the Flores Sea to the north. The Savu Sea is south of Flores, Sumba, and Timor. The Timor Sea is between Timor and Australia. From Timor to the end of the Tanimbar Islands, the Arafura Sea is to the south, and the Banda Sea is to the north.

MAJOR CLIMATIC CONTROLS.

Asiatic High. This semipermanent system (Northern Hemisphere winter) is one of the driving forces behind the northeast monsoon. A thermal high, it sets up over Asia by October and begins to shove the near equatorial tradewind convergence or NETWC (monsoon trough) southward. It is assisted in this by the North Pacific and Indian highs that shrink and move away from the area at this time of year. The Australian low, which develops over the Australian deserts at this same time, contributes to the southward movement of the trough.

Australian High. This thermal high replaces the Australian low in the Southern Hemisphere winter (Northern Hemisphere summer). It forms by early April and contributes to the northward shift of the monsoonal trough. It works in concert with the Asiatic low and the North Pacific and Indian Ocean highs, which expand northward and shift into the region.

North Pacific High. This permanent high strengthens and weakens with the changing seasons. In Northern Hemisphere winter, it weakens and allows the NETWC to move southward. When it strengthens in Northern Hemisphere summer, it contributes to the northward shift of the NETWC. In association with other major systems, it is a fundamental element of the distinctive monsoonal climate of this region.

South Indian Ocean (Mascarene) High. This permanent high intensifies and weakens with the changing seasons. At its strongest in Northern Hemisphere summer, it contributes to the airflow that moves the NETWC to its farthest north position by mid-July and its farthest south position in mid-January. It is a significant part of the monsoonal climate. Outflow from this high forms the Indian southwesterlies, a band of cross-equatorial wind flow significant to the southwest monsoon season. It is responsible for the formation of the Somali jet and partially responsible for the tropical easterly jet (TEJ).

South Pacific High. This is the Southern Hemisphere equivalent of the North Pacific high. It is farthest north and west in July when the North Pacific high is at its farthest north and west position as well. Along with other factors, it contributes to the monsoon seasons as it shifts north and south with the sun.

Subtropical Ridges. These are upper level features both north and south of the equator. Easterly flow separates them, and they shift north and south with the sun. These ridges provide outflow for the NETWC and for tropical cyclone convection. The ridges are among the components of the transition between the northeast and southwest monsoons. When they shift north, they allow the NETWC to shift north as well and bring on the southwest monsoon. When they shift south, the northeast monsoon moves south. They can also shift westward and produce breaks in the southwest monsoon.

Australian Low. This great thermal low sets up over the deserts of Australia in Southern Hemisphere summer (Northern Hemisphere winter). It pulls air in and helps the Asiatic high drive the NETWC south. The Indian and North Pacific Ocean highs are both at the weakest and furthest removed positions of the year when this low is at its peak.

Asiatic Low. This thermal low sets up over Asia in Northern Hemisphere summer (Southern Hemisphere winter). It pulls in air and helps draw the NETWC northward.

Near Equatorial Tradewind Convergence (NETWC). This is the key to the monsoonal climate of this entire region. This zone of instability travels north and south through this area with the seasons. It is formed in the convergence zone of the outflow of the Northern and Southern Hemisphere high pressure systems. In Northern Hemisphere winter (November through April), the NETWC shifts south of the Sunda Islands and brings the rainy season. In Northern Hemisphere summer (May through October), the NETWC moves well north of the islands and brings the dry season. During the otherwise dry southwest monsoon season, the southern Indian Ocean trough (SIOT) lies across western Java and brings rain to eastern Sumatra and western Java. The strength of the SIOT is inversely related to that of the NETWC; when one is strong the other is weak. Transition periods vary from one end of the island groups to the other, but the median months are April-May and October-November. The early transition (April-May) is the more unstable of the two and is more erratic in its movements. The late transition (October-November) is quieter and takes less time.

Monsoon Climate. This region is deep in the equatorial area that has a monsoon climate. While it gets more rain during the northeast monsoon, parts of it also gets plenty during the southwest monsoon. Wind direction varies somewhat from one place to another, chiefly because of terrain deflection, so the monsoons often bear different local names in different places.

The weather here is driven by the position of the NETWC. From November to April, the northeast monsoon prevails in this area. The air is lifted up the northern slopes of the mountains and brings heavy rains because of the moisture it carries with it. From May to October, the southwest monsoon takes over and sends moisture-laden air over the southern slopes of the mountains. Sumatra and part of Java have no true dry season, but the southwest monsoon does produce less precipitation. This is because the air originates over the deserts of Australia and the fetch over water on the way to the islands is shorter than the long fetch of the northeast monsoon winds. This gives less opportunity to pick up moisture from the warm, tropical waters of the Indian Ocean. The Lesser Sundas are so close to Australia, the over-water trajectory is even shorter, and the dry season is truly dry.

Monsoon Breaks. These occur during the southwest monsoon when a ridge forms over the equator and shifts northward. When this occurs, branches of the NETWC tend to develop on both sides of the equator. Disturbances such as equatorial vortices (vortexes) move along the branches of the NETWC. These disturbances bring episodes of heavy rain to Sumatra and Java because the southern Indian Ocean trough (SIOT) lies over western Java. The break ends when a mid-latitude trough moves south and shifts the ridge eastward.

Tradewind Inversion. The tradewind inversion is present year-round in this area but is stronger in the northeast monsoon season. This is because flow converges into the easterlies from the South Pacific, Australian, and Indian Ocean highs all through this area in the southwest monsoon season. The convergence weakens the inversion and convection breaks through it more easily. This relative weakness makes precipitation during the southwest monsoon possible in this area when it would otherwise be suppressed. The convergent flow also contributes to the development of the SIOT, which further indicates the weakness of the inversion. During the northeast monsoon, convergent flow is less consistent, and the inversion is more stable. The tradewind inversion (found at 6,000-10,000 feet) is part of the reason tropical cyclones do not occur close to the equator.

Tropical Upper-Tropospheric Trough (TUTT). This is a series of upper-level, cold-core lows that acts as a buffer between the north and south subtropical ridges, and it is the prime location for tropical cyclone development. During Southern Hemisphere summer (Nov-Apr), tropical disturbances and cyclones develop under the TUTT north of Australia, move westward, and sometimes brush the southern coasts of the Sundas as far west as Java and the southeastern tip of Sumatra. When this occurs, heavy rain can fall from extensive multilayered cloud cover. A very rare developing storm, which shifts far enough north before moving out into the Indian Ocean, can produce high winds on the south coasts of the islands. In this region, the prime season is from November to April, during the northeast monsoon.

El Niño. This ‘warm water’ event often causes drought in Indonesia. As the warm water that normally surrounds the islands of this region is forced eastward toward South America, cold water rises from the ocean floor to replace it. This cold water suppresses precipitation, especially convection, in part, by limiting the amount of moisture it provides the air. Another part of the equation is the intensification of the North

Pacific high. This keeps the high farther north and east than usual, which stabilizes the NETWC. The southwest monsoon rains become sporadic or cease altogether and northeast monsoon rains are disrupted as well, although not to the same degree. The more intense the El Niño, the more drastic the drought.

La Niña. This event is the opposite of the El Niño. This 'cold water' event often occurs right after the El Niño event collapses. It makes the waters off South America colder than normal, but the waters around the islands are correspondingly warmer than normal. This produces heavier rains during both the normally drier southwest monsoon and the rainier northeast monsoon.

SPECIAL CLIMATIC CONTROLS

Tropical Waves. These are easterly wavelike disturbances generated in the northeasterly trades during the northeast monsoon. They occur in a narrow belt just north of the NETWC, deepen, and move westward. They generate thick cloud layers followed by a nearly continuous wall of cumulonimbus. Many areas get their heaviest rainfall and most severe weather with a deep, well-organized easterly wave. They are most active in the vicinity of the NETWC.

Monsoon Depressions. These form near or equatorward of the NETWC in a strongly baroclinic environment with marked easterly shear. The favored location for these to form is in the South China Sea, and the favored time is the northeast monsoon season. They move west toward the southern Malay Peninsula. Widespread, heavy rain is common. Slow-moving, they can sometimes remain stationary in the area of the Malay Peninsula, which affects Sumatra and its northern islands, for days at a time before they move west into the Indian Ocean.

Tropical Cyclones. These storms come in three basic intensities, tropical depression, tropical storm, and typhoon (tropical cyclone). Sustained wind speeds at the center of the storm determine which category any one storm fits. The storm season runs from November to May and the southeastern Indian Ocean averages 7 storms per year. The area of Sumatra, Java, and the Lesser Sundas is rarely directed affected by these storms because these islands are at and close to the equator. Landfall on these islands is very rare, but cloudiness, rain, and higher winds do occur when tropical cyclones move past south of the area (see Chapter Two). The Lesser Sundas are most vulnerable, especially Timor and the islands near it. They get some weather with tropical cyclones that develop in the Banda and Arafura Seas and move westward. A secondary, less vulnerable area is south of southeastern Sumatra and westernmost Java.

Equatorial Westerlies. This is a band of westerlies that forms in the outflow of the South Indian Ocean (Mascarene) high. It is further strengthened by the Australian high, which exists during the southwest monsoon season. These westerlies provide cool, sinking air in the vicinity of the monsoonal trough, which suppresses convective activity, however, these same winds carry considerable moisture. During the northeast monsoon, the Australian low weakens or even reverses the westerlies.

Indian Southwesterlies. These winds are in a band that flows just north of the northwestern-most tip of Sumatra. These winds are associated with the southwest monsoon and form in the outflow of the South Indian Ocean (Mascarene) high.

Tropical Easterly Jet (TEJ). This is a southwest monsoon season upper air feature. It forms in the period when the ribbon of easterly winds from the North Pacific high meshes smoothly with the easterly flow across the northern edge of the Australian high and the South Indian Ocean high. The TEJ disappears in Southern Hemisphere summer when the Australian low (a thermal low) forms and disrupts the smooth flow of easterlies. This jet provides an outflow mechanism for the NETWC, which causes precipitation in western Java and along the southeastern coast of Sumatra when the SIOT is there.

Tradewind Belt. The tradewind belt is a zone (between 20° N and 20° S) of constant easterly wind through this area. A result of outflow from the North and South Pacific highs, the tradewinds feed tremendous amounts of moisture into this area all year. Stronger in the southwest monsoon season than in the northeast monsoon, the trades flow under the tradewind inversion.

Somalia Jet. This is a low-level jet that flows north to northeast along the African eastern coast. Although it is quite distant from this region, it still influences weather during the southwest monsoon because it is a driving force behind the equatorial westerlies.

Diurnal Wind Circulations.

Land/Sea breezes. These local wind systems are fundamental to the circulation around the islands. Locations on the northeast plains of Sumatra have the weakest land/sea breeze because of the low contrast between land and sea temperatures. Much of the plain is quite low and marshy. Places where the mountains are close to the coast have the strongest land/sea breeze as the temperature contrast is greater, especially at higher elevations. The south coast of Sumatra, with its steep ridge of volcanic mountains, has the strongest land/sea breeze.

Mountain/Valley and Slope Winds. Like land/sea breezes, mountain/valley winds are strongest where the temperature contrast is greatest. Sumatra and Java have the most mountains and the most land mass, so they have the strongest mountain/valley winds. They also have the most foehn winds. Sumatra has foehn winds more than Java.

Convergence Zones. Convergence zones are responsible for lines of thunderstorms just off the coasts of the mountainous islands. A sumatra is a typical example of what happens in a convergence zone. Most occur at night when the cool air from the mountains flows downslope and out over the sea to collide with seasonal flow. Those on the north side of the islands occur during the northeast monsoon and those on the south side of the islands occur in the southwest monsoon. A secondary type of convergence zone occurs downwind of a terrain feature, such as a mountain or hill. The air splits on the upwind side and reconverges on the downwind side. The air is so moist, the result is an area of rainshowers and thunderstorms. Sumatra, Java, and Bali have the most of this type of convergence zone convective activity.

Sumatras. A sumatra is a line of thunderstorms that marches down the Strait of Malacca and dissipates off the coast of western Malaysia. During the southwest monsoon, mountain breeze winds trigger these storms. The cooler air glides down the mountains overnight and goes out over the water. The contrast between the mountain air and the over-water air creates the equivalent of a cold front and thunderstorms build quickly. Most sumatras last an average of only 2 hours, but these lines of thunderstorms can travel at up to 40 knots.

Foehn. Locally called a ‘bohorok,’ a foehn blows in the area of Medan during the southwest monsoon season (dry season). This hot, arid wind is the result of downslope from the high mountains to the south of Medan on Sumatra. A bohorok can wither crops very quickly. Foehns are also common on the northwestern end of Sumatra in the same season. Other locations similarly placed in relation to mountains are just as likely to experience these same conditions. Foehns are of interest because they dry vegetation so much, fires start very easily.

Squalls. These are strong winds generally associated with lines or bands of thunderstorms. They rise suddenly, increase in speed rapidly, then fall off quickly. Those associated with stationary thunderstorms (such as those in reconvergent flow around a mountain) tend to occur in the late afternoon or early evening. Those associated with moving lines of thunderstorms (such as those with a sumatra) tend to occur at night.

General Weather. By November, the Asiatic low has been replaced by the Asiatic high. At the same time, the North Pacific, South Pacific, and South Indian Ocean highs are all farthest east and south. The thermal high over Australia has been replaced by a thermal low. This combination pulls the NETWC into its annual farthest south position during the northeast monsoon. It lies across the island chain by December and shifts south of the islands in January. In conjunction with that, the northeast monsoon brings onshore flow to the north coasts of the islands and the north slopes of the mountains. This moisture-laden air is lifted to form massed clouds over the mountains and rain is abundant everywhere. At the height of the northeast monsoon, the highest peaks get more than 30 inches (760 mm) in a month. Sumatra and Java have the most precipitation, and there is a steady reduction in amount from west to east beyond that.

The transition from the northeast monsoon to the southwest monsoon (March and April) is far more unstable than the transition the other way (October and November). More convection occurs with the NETWC as it oscillates across the islands many times before it finally moves north of the area. The transition begins as early as the end of February on Timor and as late as the end of April on Sumatra and is over everywhere by the end of May. The east islands are in the southwest monsoon as much as 2 months earlier than the northwestern tip of Sumatra. The transition from the southwest monsoon to the northeast monsoon is quieter and takes less time. It begins in October on Sumatra and Java and in early November on Timor; it is over everywhere by the end of November.

A thermal high sometimes develops over India in the northeast monsoon season and creates an area of stronger northwesterly flow over the Bay of Bengal. Although this flow does not extend south of 5° N, the northwestern end of Sumatra gets a marked increase in rain. Because the high is shallow, it rarely reflects above the 1,000-mb level on synoptic maps.

Monsoon depressions and tropical waves both favor the northeast monsoon season. Monsoon depressions form near or equatorward of the NETWC and move west out of the South China Sea to over the Malay Peninsula and track into the Indian Ocean. They produce heavy rain over a wide area for days at a time. Tropical waves occur in a narrow belt just north of the NETWC and move westward. They produce widespread, thick layers of middle and high cloud followed by a dense wall of cumulonimbus. Periods of heavy rain and severe weather occur when they are deep and well-organized.

During El Niño years, the water around the islands is unusually cold, which disrupts the normal development of cloud. This cold water suppresses convective activity and can result in very serious precipitation shortfalls. The problem becomes serious for two reasons. One, the crops grown on these islands are water-dependent and suffer from drought early in the cycle. Two, the local farmers still practice slash and burn farming, which strips the land of vegetation that could hold moisture in the soil. Forest fires, crop losses, and famine result. The problem is not solved when the rains return in the next wet season. Soil erosion and devastating floods become endemic to the islands. The other side of the El Niño cycle is the La Niña, which is when the waters in this area are warmer than usual. This leads to more precipitation than normal, in some instances, considerably more. If a La Niña year comes right behind an El Niño year, the flooding can be catastrophic.

Tropical cyclone activity is of little concern. The tradewind inversion is partly responsible for this as it tends to cap convection. At most, the islands will sometimes be brushed by the outer edges of tropical cyclones that pass south of the area. Timor and the other Lesser Sundas are prone to getting more precipitation when tropical cyclones pass south of them through the Arafura and Timor seas. The southern coasts of Bali, Java, and southeastern Sumatra are less vulnerable, but still occasionally get extra rain from a passing Southern Hemisphere tropical cyclone as well. On rare occasions, tropical cyclones are strong enough and far enough north to produce high winds and heavy seas on the southern coasts of the islands.

Sky Cover. Overall cloudiness is greatest during the northeast monsoon, in the afternoon to early evening on the windward slopes of mountainous terrain. Despite the advection of moisture onto the land, very low ceilings are not common except with thunderstorms and rainshowers. Most cloud is cumulus, stratocumulus, and altocumulus. Cirrus is generally associated with thunderstorms. Most ceilings reach the diurnal maximum in the afternoon hours and the minimum overnight and in the early morning hours before dawn. Figure 3-3 shows the occurrence rate of ceilings below 3,000 feet for representative locations throughout the islands. From Sumatra to Timor, the month with the maximum cloud cover varies from November-December for Sumatra to January-February for Bali, to February-March for Timor. This is related to the NETWC. In the early season, it is closest to Sumatra. Later, it is farther south and reaches Timor more effectively.

Ceilings below 10,000 feet are mainly composed of low cumuliform clouds, but middle cloud ceilings form when tropical waves or disturbances move through. Cloud bases average 3,500-6,500 feet when the cover is cumulus or stratocumulus and 8,000-10,000 feet with altocumulus or altostratus. Location relative to blocking mountains is important to how much of this higher cloud occurs. Leeside locations typically have less than windward sites. Windward locations on Sumatra and Java have ceilings below 10,000 feet 25-35 percent of the time in off-peak hours and 65-75 percent of the time in the late afternoon through early evening. Leeward sites have lower occurrence rates, 5-15 percent of the time on off-peak hours and 15-25 percent of the time in the maximum cover hours. For windward sites in the Lesser Sundas, ceilings below 10,000 feet occur 15-25 percent of the time for most hours and up to 35-45 percent of the time in late afternoon and early evening. Leeward sites have these ceilings considerably less often, 5-10 percent of the time for most hours and 15-25 percent of the time for peak hours.

Ceilings below 3,000 feet occur most often in the late afternoon through evening hours and least overnight. Sumatra and Java have the highest rates of occurrence of these ceilings. The small islands around Sumatra and Java are next and the Lesser Sunda islands have the lowest occurrence rates. Rengat, on Sumatra's eastern plain, has ceilings below 3,000 feet 55-65 percent of the time throughout the day and a maximum of 78 percent of the time between 1500-2000L. This is because the tropical forest that surrounds Rengat provides additional moisture through evapotranspiration and the marshy ground also contributes. Most other places on Sumatra and Java range around 15-25 percent of the time for most of the day with peak cover at 30-40 percent of the time in the late afternoon to evening. In the Lesser Sundas, ceilings below 3,000 feet occur 15-25 percent of the time most of the day and 25-35 percent of the time in the late afternoons and early evenings. Places in the lee of a mountain have these ceilings less than 5 percent of the time. The leeside locations in the Lesser Sundas are most likely to have low occurrences. Ceilings at this level form from dissipating cumulus and stratocumulus.

Ceilings below 1,000 feet generally rarely occur anywhere. In most places, they are usually associated with thunderstorms and rainshowers. Outside of that, ceilings below 1,000 feet occur briefly around sunrise in places surrounded by marsh lands, rivers or both. Telukbetung, on the southwestern tip of Sumatra, is typical of this. It lies in a rain forest area laced with the many mouths of a river that drains to the sea. Even here, the ceilings occur most in the rainy season, about 15 percent of the early morning hours, and burn off within a couple of hours of sunrise. Pakanbaru/Simpantiga (Sumatra), deep in a tropical marsh, has them 22-28 percent of the time in the morning and well under 10 percent of the time the remainder of the day. Most tropical forest locations usually have ceilings below 1,000 feet 5-10 percent of morning hours (between sunrise and 0900L) and rarely the rest of the day. Mountain slopes are likely to be shrouded in clouds when they are windward, and relatively cloud-free when leeward. Cloud cloaking is most likely above the 3,000-4,000 foot level in the mountains. Where cloaking occurs varies with the lifting condensation level and location relative to the wind.

Ceilings below 500 feet occur rarely. The exceptions have short term ceilings in the morning hours. These locations are surrounded by tropical forest and have 'tropical forest stratus' (so named because it hangs in the treetops). Typical of this is Palembang, on Sumatra. It is in the great eastern plain and lies on marshy ground between two rivers. It has ceilings below 500 feet up to 11 percent of the time between sunrise and 0900L. Pakanbaru/Simpangtiga, also on Sumatra, has them 20-25 percent of the time in the morning hours. Like Palembang, it is in the eastern plain and is surrounded by marshy land and several rivers. The more tropical forest vegetation surrounds a location, the more likely it is to have low ceilings in the morning hours.

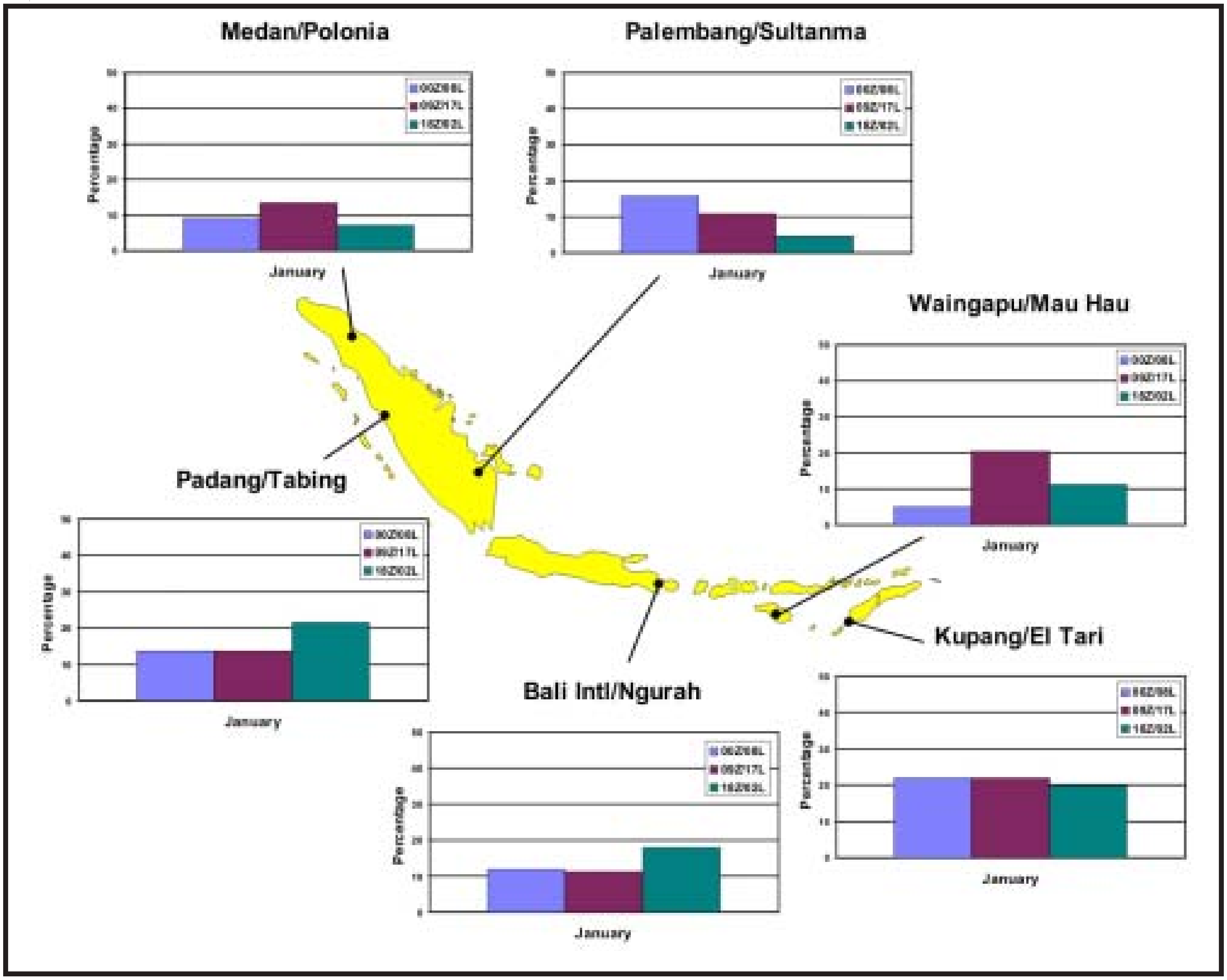

Figure 3-3. Northeast Monsoon Season Percent Frequency of Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Haze and rain restrict visibility more than fog. Rain clears haze from the air, so haze lowers visibility the most in the dry season months of May through October. Salt haze, however, is ever-present, even in the rainy season, although it does not generally lower visibility below 6 miles (9,000 meters). In El Niño years, when rains are short, haze, smoke and air pollution can reduce visibility to below 1 mile (1,600 meters) for long periods. See Figure 3-4 for occurrence rates of visibility below 3 miles (4,800 meters). On mountain slopes above the 3,000-4,000 foot (900-1,200 meters) elevation level, cloud cover frequently cloaks the windward side. When this occurs, visibility will remain between 1 and 1/2 mile (1,600-800 meters) indefinitely in cloud. As a general rule of thumb, the larger the island, the greater the occurrence of low visibility.

Sumatra and Java. Visibility below 4,800 meters occurs most in the eastern plain of Sumatra and the least at leeside locations on either island. While windward or leeward location is important, a windward site close to the coast or on relatively dry ground will still have low instances of visibility below 4,800 meters. Terrain plays an important role. Overnight, Rengat/ Japura, on Sumatra, has visibility below 4,800 meters 65-70 percent of the time in the mornings but only 5-10 percent of the time the rest of the day. The combination of windward location, marshy ground, and tropical forest creates the perfect environment for morning fog. On Sumatra, most places that get morning fog average 20 percent of the time or less in the mornings and under 5 percent of the time the rest of the day. The remaining island locations average visibility below 4,800 meters 10-15 percent of the time from sunrise to 0900L and rarely get it the rest of the day. Java has fewer occurrences. Even places inclined to morning fog only get them 10-15 percent of the time between sunrise and 0900L and well under 5 percent of the time the rest of the day. Other places average visibility is below 4,800 meters 2-5 percent of the time in the mornings and not at all the rest of the day.

Visibility below 1,600 meters occurs most often in the eastern plain of Sumatra and the least in leeside locations on either island. Most locations do not have visibility below 1,600 meters, but those that do get it most frequently in the early mornings. Places surrounded by tropical forest and marshy ground get the highest occurrence, as much as 25-35 percent of the time in the mornings. Pakanbaru/Simpangtiga is an example of this extreme. Most places that get morning fog average 10 percent of the time and under with no occurrences after the fog burns off except in convective precipitation. Even there, visibility improves rapidly and remains above 1,600 meters the rest of the day outside of rainshower and thunderstorms activity. In El Niño years, when conditions are abnormally dry, low visibility occurs most often. Visibility can be under 1,600 meters for months at a time because of pollution, smoke and salt haze.

Visibility below 1/2 mile (800 meters) occurs rarely in most places. Tropical forest sites have visibility below 800 meters in the morning hours 7-17 percent of the time and drop off quickly to nothing for the rest of the day. A classic example of this is Pakanbaru/ Simpangtiga, on Sumatra, which has visibility below one-half mile up to 17 percent of the time between sunrise and 0900L, then improves quickly the rest of the day and has visibility below 800 meters rarely. Its nearest equivalent on Java is Malang (Abdulrachman), which gets visibility below 800 meters 7 percent of the time right at sunrise and then it does not have it at all for the rest of the day.

The Lesser Sunda Islands. Visibility below 4,800 meters occurs under 5 percent of time at all hours, with the maximum occurrence from sunrise to 0900L in fog. Haze visibility sometimes drops visibility below 4,800 meters in dry periods. In El Niño years, when conditions are abnormally dry, low visibility in haze is most likely. In a severe El Niño, visibility can remain below 1,600 meters for weeks on end in a noxious soup of pollution, smoke and salt haze.

Visibility below 1,600 meters occurs rarely regardless of the time of day from Bali to Timor. Visibility this low occurs either with early morning fog or with convective precipitation. In both cases, duration is short. With fog, visibility improves within an hour or so after sunrise. With convective precipitation, visibility drops for an average of one-half hour or less.

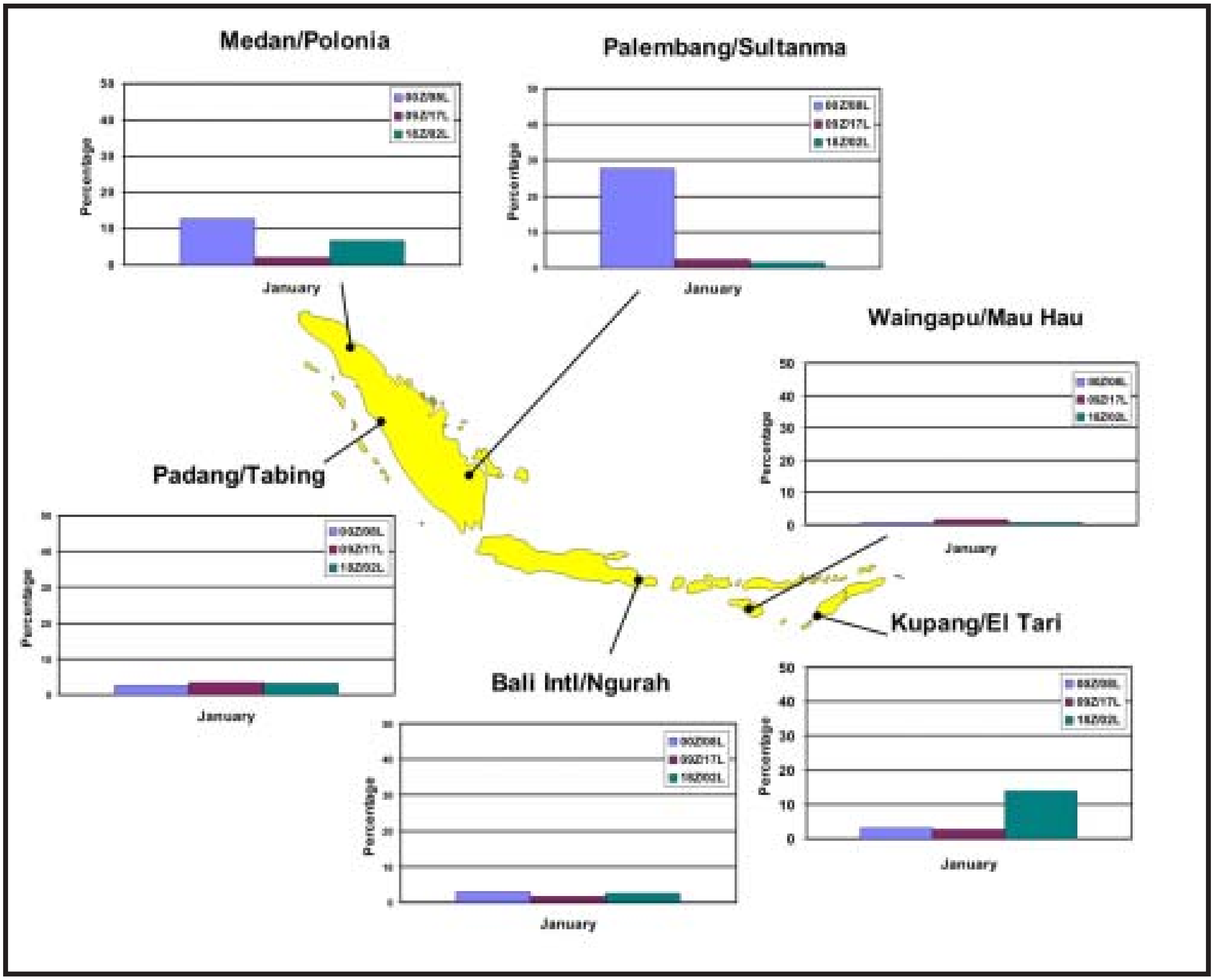

Figure 3-4. Northeast Monsoon Season Percent Frequency of Visibility below 3 Miles (4,800 Meters) for November to April. The graphs show a monthly breakdown of the percent of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Although overall flow is from the northeast monsoon winds, local terrain plays a significant role in both direction and speed. The farther a location is from the mountains, the less effect a land/sea breeze has. This is especially true in the Sumatran eastern plain, the broad, flat area that constitutes the whole northeastern two-thirds of the island. The near-equal temperature of land and sea in this area stills the wind and makes conditions oppressively hot and humid. Closer to the mountains, a fresh mountain breeze keeps the air cooler and drier. The smaller the island, and the lower the elevation, the more limited the land/sea breeze. Islands that are no more than coral atolls or are quite low, generally have the winds of the current monsoon regime, in this season, northeasterly. Wind speed varies somewhat, but averages 5-8 knots in most places. Speeds are higher during the day than at night. The surface wind roses shown in Figure 3-5 are for locations throughout the islands. Record winds range around 85-95 knots and are associated with thunderstorm downrush gusts or tropical storms that brush past the islands.

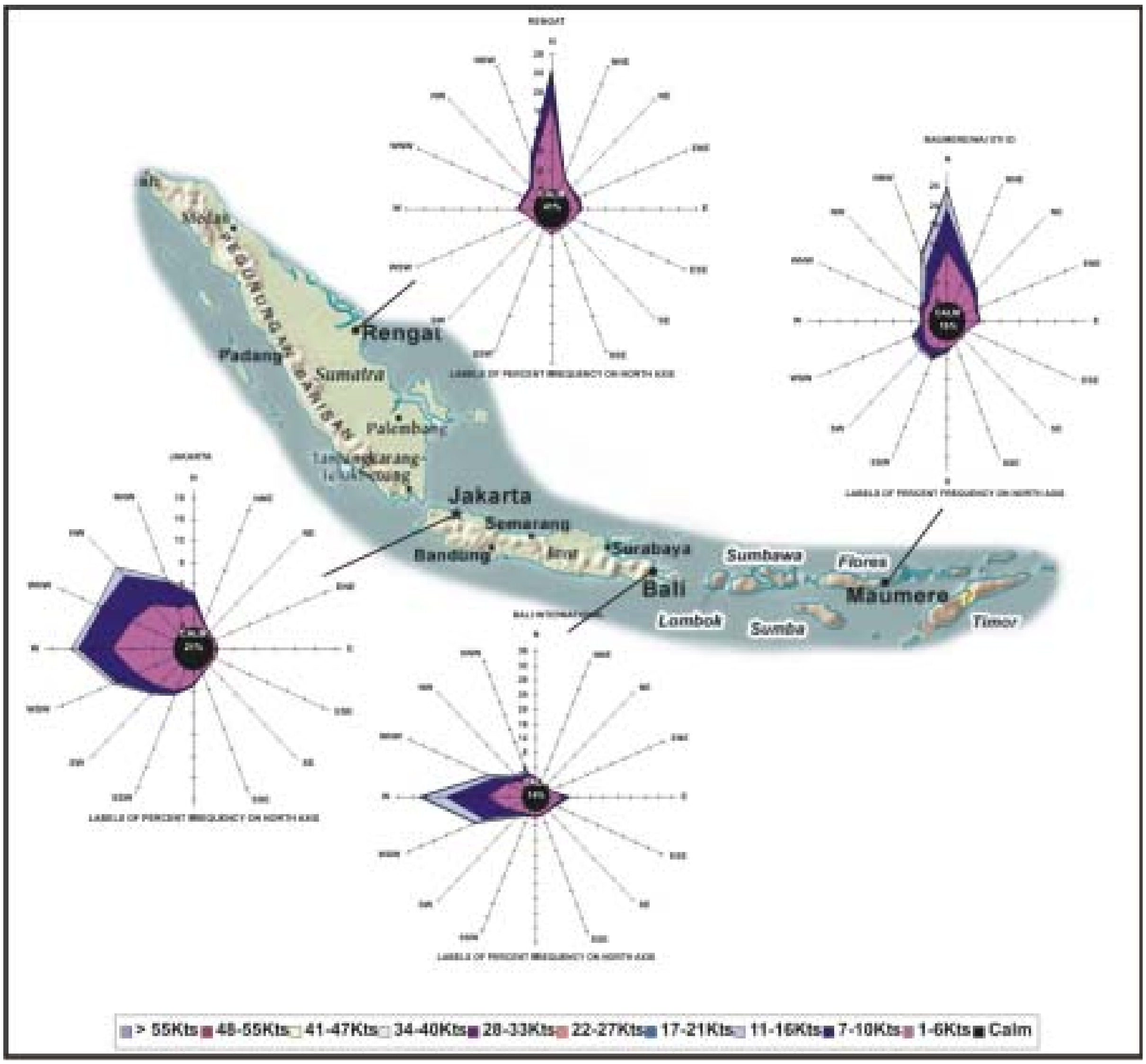

Figure 3-5. January Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Air Winds. This area is overlain by three different wind systems. The lowest is the monsoon flow. The northeast monsoon wind system is only 8,000-10,000 feet deep (from the surface) north of the equator and around 20,000 feet south of the equator. The northeast monsoon tends to be more easterly north of the equator and more northerly south of the equator. Between the monsoon flow and the tropopause, tropical easterlies dominate. Above the tropical easterlies (above the tropopause), layers of persistent easterlies alternate with persistent westerlies. The layers slowly sink toward the tropopause and dissipate, so there is a steady oscillation (over 2 years) between easterlies and westerlies at the top of the tropopause. Speeds typically average 10-15 knots at low levels, do not exceed 20 knots even at 300 mb, and remain below 40 knots up to 150 mb. Figure 3-6 shows upper-air wind roses for selected locations..

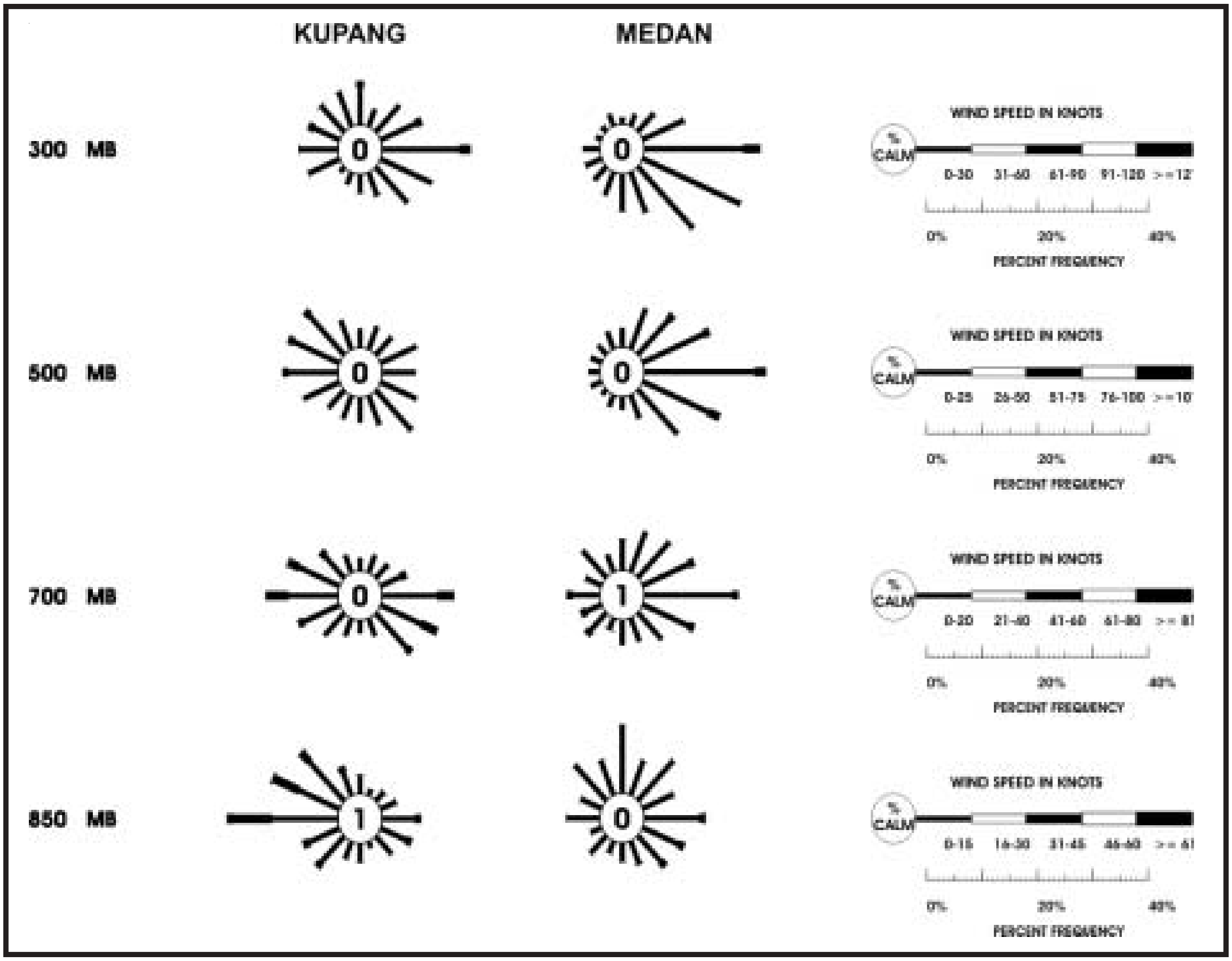

Figure 3-6. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at selected locations.

Precipitation. This season has the most rain days and generally more accumulated precipitation than the dry season. This is also the season of maximum thunderstorm occurrence. The most thunderstorms occur in the transition from the northeast monsoon to the southwest monsoon during March and April. Because of upslope, most thunderstorms occur on the windward side of the mountains and the least on the north coast. Although thunderstorm activity is probably a daily occurrence in the high mountains (windward slopes), the isolated nature of the terrain makes confirmation of specific numbers impossible. Figure 3-7 shows the mean precipitation amounts for January, generally the peak precipitation month during the northeast monsoon season. Figure 3-8 shows the mean days for rain, thunderstorms, and hail at selected locations.

Tropical cyclones approach the area from the south. Storms that make landfall anywhere in the islands are extremely rare, but some brush past just south. The Lesser Sundas are most vulnerable. Sumatra and Java are less so, but they do get heavy rain episodes from passing storms. Easterly waves sometimes move through the northeast trades just north of the NETWC. They produce extensive cloudiness and rainshowers and thunderstorms over a broad area. Duration of the precipitation event varies with the speed of the waves, but the bad weather clears quickly once waves leave the area. The north sides of the islands are vulnerable.

Sumatra and Java. At windward locations on both islands, it rains 15-20 days per month and up to 25 days per month at some locations close to or in the mountains. At leeward locations, an occurrence rate of 10-15 days of rain is normal. At higher elevations in the mountains, it is likely to rain at least part of every day. The north coast of Sumatra gets an average of 8-10 inches (200-250 mm) of rain per month from November to January, with the peak amount in January. Amounts start to fall off in February but never go much below 4 inches (100 mm). The average is between 6 and 8 inches (150-200 mm). The northwestern end of Sumatra has the lowest amount (between 4 and 5 inches or 100-125 mm) and the rest of the north side ranges between 6 and 8 inches (150-200 mm) with a few areas up around 10-12 inches (250-300 mm). Places in higher terrain have the highest amounts. On Java, all but the central mountains average 6-8 inches (150-200 mm) of rain in November and December, then get 10-12 inches (250-300 mm) of rain per month from January to March. Depending on elevation, the mountains get 15-25 inches (400-650 mm) of rain per month and the highest peaks get as much as 30 inches (760 mm) of rain in a single month. The windward slopes of the Sumatran and Javan mountains get the most precipitation. The highest peaks get more than 30 inches (760 mm) of rain in the peak month of January. The upper reaches of the mountains on Sumatra consistently get more than 20 inches (500 mm) of rain per month throughout the rainy season.

Surprisingly, leeward coastal sites on Sumatra and Java often have thunderstorms and abundant precipitation during the northeast monsoon. The NETWC lies right along the line of islands and this, along with local wind effects, causes rain. On the north coast, the plain is close to sea level, and even under direct onshore flow, there isn't enough upslope lifting to fire thunderstorm activity. On the south coast, however, local land/sea and mountain breezes feed moisture into the mountains and help trigger thunderstorm activity in the unstable air of the NETWC. They occur later in the day on the windward slopes of the mountains and come down the slopes to the coastal areas with the cooler mountain air flowing downslope in the evenings. From November to April, the leeward coasts get 12-14 inches (300-350 mm) of rain per month.

The Lesser Sundas. The amount of monthly rainfall jumps dramatically between November and December, and the peak accumulation comes in January. From Bali to Flores, November rainfall averages 4-6 inches (100-150 mm). East of Flores, the average is only 1-3 inches (25-75 mm). In December, rainfall jumps to 6-9 inches (150-230 mm) throughout the Lesser Sundas. January rainfall rises to the peak of 8-12 inches (200-300 mm) per month with spotty areas of up to 15 inches (380 mm) per month on windward slopes (especially on Bali). Kupang, on the southern end of Timor has over 15 inches (380 mm) of rain in January and almost 14 inches (350 mm) in February. March and April amounts reflect the start of the NETWC northward shift. Rainfall east of Flores drops to 5-9 inches (125-230 mm) in March with the most on the southeast end of Timor under onshore flow. From Bali to Flores, rainfall drops to 6-10 inches (150-250 mm) in March. By April, rainfall east of Flores averages 3-4 inches (75-100 mm) except for the northeast windward half of Timor, which gets 6-8 inches (150-200 mm) in April under southwest flow. From Bali to Flores, rainfall averages 3-4 inches (75-100 mm) in April. On mountain slopes, especially on Bali, rainfall can still exceed 12 inches (300 mm) in April.

The number of rain days peaks with the passing of the NETWC. This varies from one end of the island chain to the other. Sumatra and Java have the most rain days in November to January, but the Lesser Sundas have the most rain days in January through April. Terrain also plays a part; locations in or near the mountains have more rain days than those on the coasts and plains. Sumatra and Java average 10-15 days with rain in November through January then 7-12 days with rain in February through April. Some windward locations in the mountains on both islands get as many as 20 rain days per month throughout the northeast monsoon. In the Lesser Sundas, November through January average 3-7 rain days. February through April average 7-12.

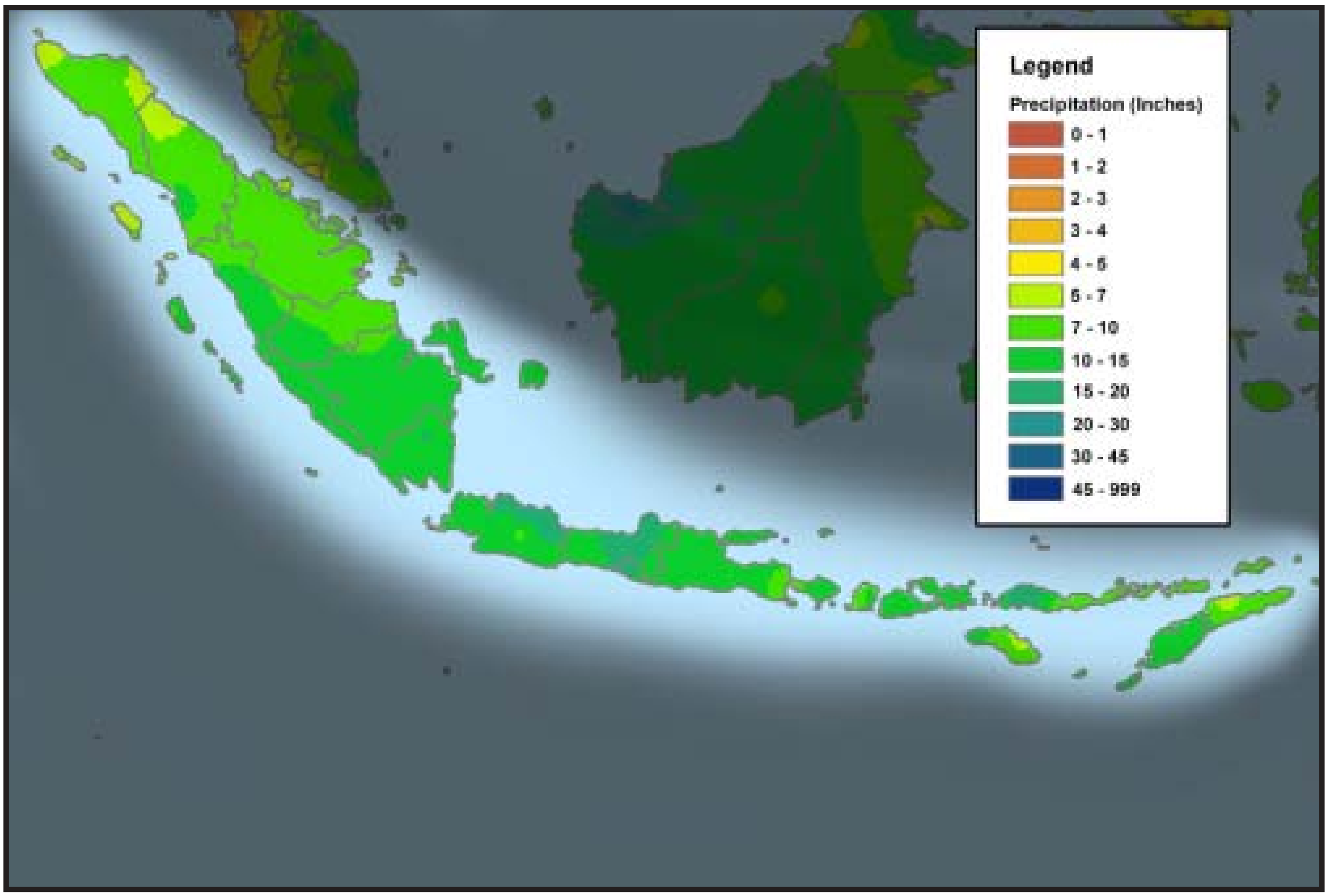

Figure 3-7. January Mean Precipitation. The figure shows mean precipitation in the region.

Leeward locations in the Lesser Sundas are more dramatically affected by terrain than on Sumatra and Java. Places on the leeside of mountains and hills often have only half the average number of rain days of windward locations, sometimes only 2-4 days per month throughout the northeast monsoon season.

This season is the time of annual thunderstorm maximums. Thunderstorms are most frequent in March and April from Sumatra to Bali when the NETWC is at its most unstable and oscillates across the islands as it begins its shift northward. From Lombok to Timor, the peak occurrence is from late November to January. Thunderstorms occur most in places in or near mountains and the least on coasts and in plains. There are no locations outside the mountains that record any hail on a regular basis. A few places in and near the mountains report soft, small hail once every 2-5 years with very powerful thunderstorms. High mountain locations get thunderstorms almost every day. Outside of the mountains, thunderstorms average 4-9 days per month in November to January from Sumatra to Bali and 7-14 days per month from February to April. In the mountains, thunderstorms can occur as much as 15-20 days a month; location relative to wind flow is the deciding factor. From Lombok to Timor, the islands average 8-12 thunderstorm days in November through January. Mountainous locations have as many as 22 thunderstorm days a month. The number drops off after that to a mean of 3-8 days per month in February through April. Mountainous locations are still higher but also drop, to an average of 10-15 days per month.

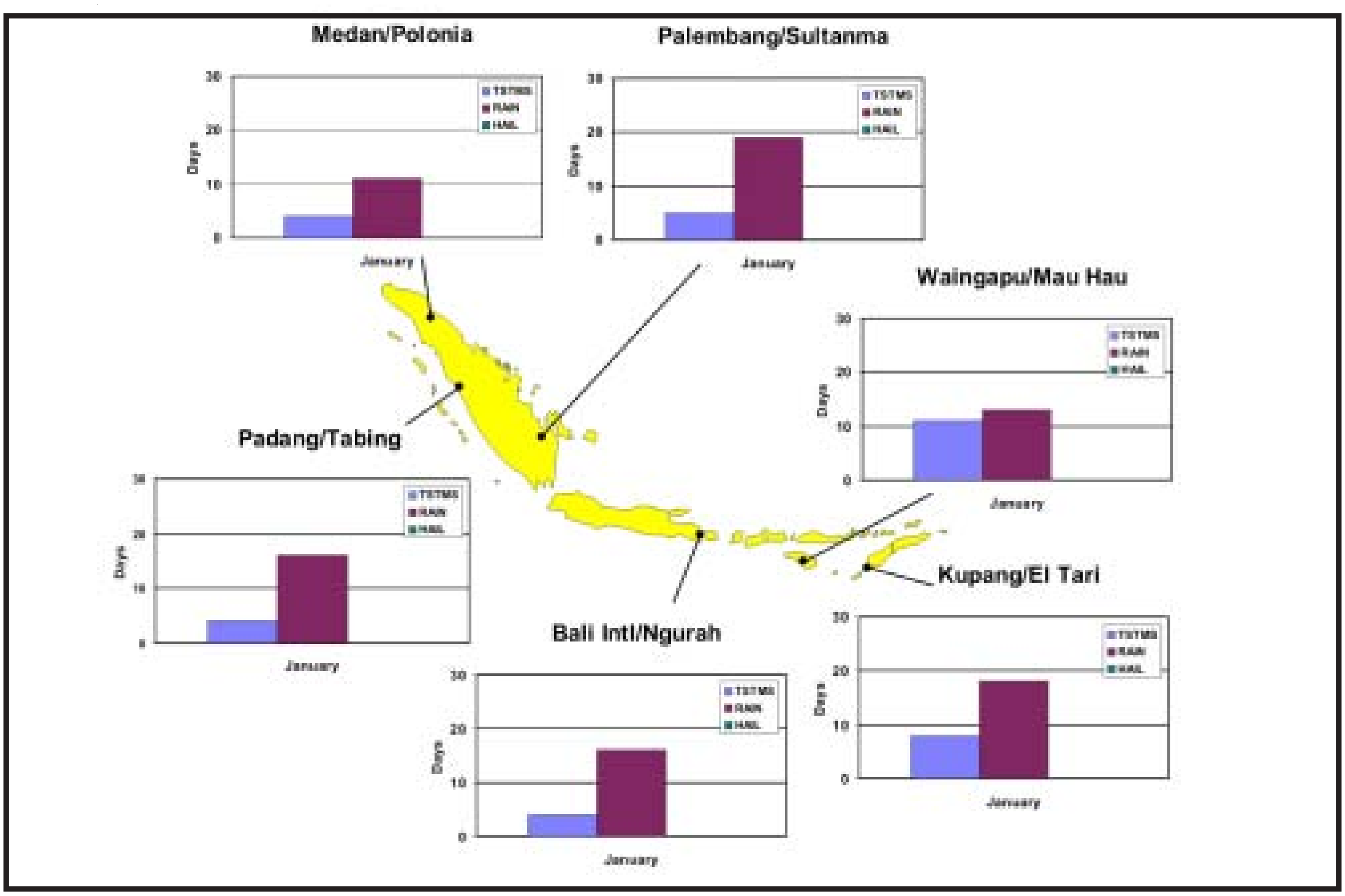

Figure 3-8. Northeast Monsoon Mean Precipitation and Thunderstorm Days, from November to April. The graphs show the average seasonal occurrences of rain, thunderstorm, and hail days for representative locations in the region.

Temperatures. Temperatures vary far more diurnally and with elevation than with season. Mean high temperatures consistently range between 82° and 87°F (28° and 31°C). Most places are right at 86°F (30°C). The mean lows range from 73° to 77°F (23° to 25°C) with most places around 75°F (24°C). Temperatures cool moist adiabatically with elevation, roughly 3 Fahrenheit degrees per 1,000 feet (1.65 Celsius degrees per 300 meters). Places under windward flow have more cloud and are cooler than those places on the leeward side of the mountains. Leeward sites generally have the hottest extreme high temperatures. Throughout the islands, temperatures rise above 95°F less than one day all season. Extreme highs range from 98° to 111°F (37° to 44°F) at leeward sites in association with foehns. These hot, dry winds wither crops within hours. Most places vulnerable to them average only 1-3 days with foehns per year. Jatiwangi, on Java, is partly encircled by mountains and is one of the few places that gets foehns year-round. It gets a mean of 7 foehn days per year, 1-2 days of that in the northeast monsoon season. Windward locations have moderated extreme highs, in the 91° to 100°F (33° to 38°C) range. Extreme lows are associated with cold surges that pass through the area most in December through February, the height of the northeast monsoon season. The extreme lows range between 59° and 71°F (15° and 22°C) with the lowest temperatures in December through February. Most places are at the high end of the range, around 68°F (20°C). See Figures 3-9 and 3-10 for January mean maximum and mean minimum temperatures.

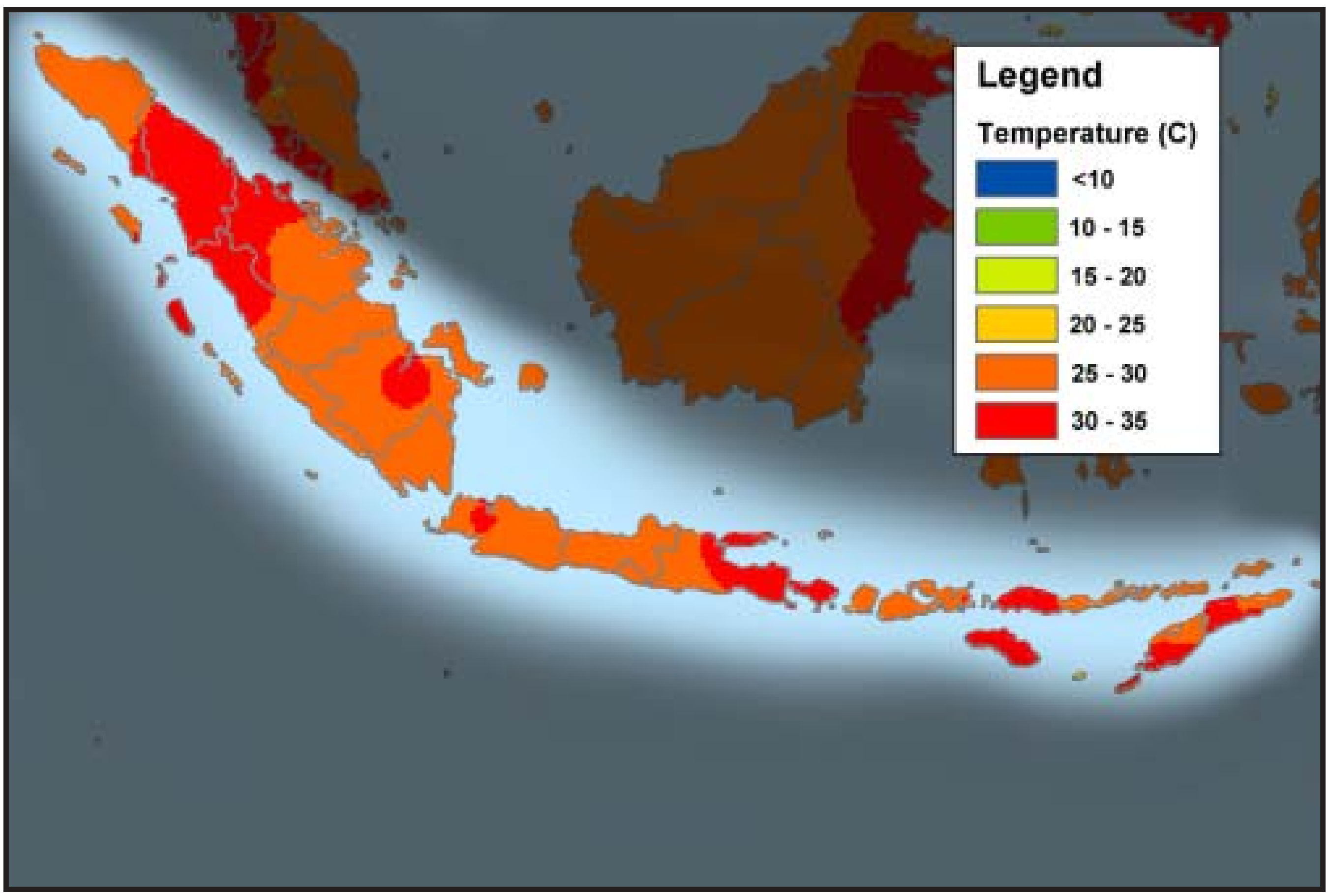

Figure 3-9. January Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for a representative month of the northeast monsoon season. Daily high temperatures are often higher than the mean. Mean maximum temperatures during other northeast monsoon season months may be higher or lower, especially at the beginning and ending of the season.

Figure 3-10. January Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for a representative month of the northeast monsoon season. Daily low temperatures are often lower than the mean. Mean minimum temperatures during other northeast monsoon season months may be higher or lower, especially at the beginning and ending of the season.

Hazards. Thunderstorms, foehns and torrential rain episodes are the major hazards. Thunderstorms are typically 35,000-45,000 feet tall with a few tops above 50,000 feet. Cells this large produce teeming rains, moderate-to-severe in-cloud turbulence, and powerful downrush winds. Hail does occur in these storms, but it is not common because of the deep layer of warm air. Generally small and soft, hail does little damage. Icing in cloud is confined to the upper reaches of the cloud, where the temperature falls below 32°F (0°C). Although most common in the southwest monsoon season, foehns do occur on the lee coasts of Sumatra and Java during the northeast monsoon. These winds can cause structural damage or trigger fires because they are so hot and dry, they wither vegetation to tinder. Torrential rains, which can produce flooding, occur regularly. The windward slopes of the mountains get the most precipitation and have the highest single rain event totals as well. This massive amount of water draining into the lowlands causes rivers to rise above their banks very quickly. In the marshy areas, the extra water is quickly dispersed. Also, the swiftly flowing water itself can be dangerous as it washes away roads and bridges, and causes mud slides. The danger is greatest where forests have been clear cut or slash and burn farming techniques have stripped vegetation from the soil.

Tropical cyclones are not a serious threat to this region, however, some occasionally pass close enough to the southern coasts to bring widespread, heavy rains. If a tropical disturbance is developed enough when it passes through the Timor and Arafura seas, it can also bring high surf and strong winds. Java and Sumatra are less vulnerable, but can still get rain and wind from a storm far enough north to brush them. Convergence lines of thunderstorms form off shore the larger islands when mountain flow slides off the coast and collides with prevailing northeasterly flow. The resulting line of thunderstorms, sometimes called sumatras, can move very quickly and march off to the east-northeast very quickly; they can travel at speeds up to 40 knots.

Trafficability. Trafficability varies widely with location. In tropical forests, movement is difficult at best, and in this wet season, flooding makes anything but boat travel almost impossible. Mountain tracks and roads are often washed out by heavy rains and bridges are frequently damaged, unsafe, or vanished altogether. Mudslides and washouts render roads impassable most often in the highlands. Flooding restricts travel in the marshy plains.

General Weather. During April and May, the Asiatic high is replaced by the Asiatic low. At the same time, the thermal low over Australia is being replaced by a thermal high. The North Pacific high grows stronger and shifts to its farthest north position by mid-June as do the South Pacific and South Indian Ocean highs. This combination results in the equatorial westerlies that converge with the steady, broad band of easterlies (trades). A hallmark of the season is the Somali jet, which forms along the eastern African coast and drives moisture into the equatorial westerlies. In this season, the NETWC is well north of the area and allows southwest flow well north of the equator. The SIOT is a convergence zone between the South Indian Ocean high and the Australian high. The zone lies between Sumatra and Java and fires convective activity in that area. The southwest monsoon season is at its peak intensity in July and August. After that, the NETWC begins its return to the south. The southwest monsoon is the driest time of year. The tradewind inversion is weak and convection breaks through more easily, which is why precipitation occurs in this period at all in the Lesser Sundas.

The transition from the northeast monsoon to the southwest monsoon (March and April) is far more unstable than the transition the other way (October and November). More convection is associated with the NETWC as it wavers across the islands many times before it finally moves north of the area. The transition is over everywhere by the end of May. The east islands are into the southwest monsoon as much as 2 months earlier than the northwestern tip of Sumatra. The transition from the southwest monsoon to the northeast monsoon is quieter and takes less time. It begins in October on Sumatra and Java and in early November on Timor; it is over everywhere by the end of November.

On Sumatra and the western end of Java, the dry season is not really the best term for this period. While the northeast monsoon produces more rain for the whole chain of islands, for Sumatra and Java, the southwest monsoon has less in only relative terms. Part of the cause is the SIOT, which settles over western Java. That, plus the long, over-water fetch of the southwest monsoon winds from Australia allows the Indian Ocean to modify the air. This results in convection on the south end of Sumatra and on the slopes of Javan mountains.
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This is not true of the Lesser Sundas. The Lesser Sundas go nearly dry in the southwest monsoon months. This is partly because the air from Australia has a short trajectory over water and is still relatively dry. Also, the smaller islands have fewer obstructions to wind flow that cause upslope convection. The third reason is the equatorial ridging that sets up over these eastern islands. The SIOT, oriented north-south, lies over the west end of Java and fires convection but does not reach the Lesser Sundas. The SIOT and its associated convection are strongest when the TEJ is strong and the easterly flow around the Southern Hemisphere highs is well-established. Both ribbons of easterlies feed moisture into the area.

During El Niño years, the water around the islands is unusually cold, which disrupts the normal development of cloud. The southwest monsoon, normally dry anyway, is even drier. Even Sumatra and Java can go almost rainless through the entire season. This creates drought, water shortages and air pollution problems. Only the rains of the next rainy season can clear the air. La Niña, which is the warm water part of the El Niño cycle, leads to more precipitation than normal. In some instances, the islands get considerably more rain than usual, even in the dry season. If a La Niña year comes right after an El Niño year, the flooding could be catastrophic.

Tropical cyclone activity is of little concern, but the islands will sometimes be brushed by the outer edges of tropical cyclones that pass south of the area. Timor and the other Lesser Sundas are prone to more precipitation when tropical cyclones pass south of them through the Arafura and Timor seas. Bali, Java and Sumatra are less vulnerable, but still occasionally get rain from a passing Southern Hemisphere tropical cyclone. On rare occasions, tropical cyclones are strong enough and far enough north to produce high winds and heavy seas on the southern coasts.

Sky Cover. Cloud cover is at its annual minimum in this season, especially in the Lesser Sundas. Although the NETWC is well north of this area, the SIOT is present, and it brings cloud cover to the south end of Sumatra and the west half of Java. The Lesser Sundas do not see much of that. They are at their driest time of the year and the cloud cover reflects that. See Figure 3-11 for a sample of occurrence rates of ceilings below 3,000 feet. Most cloud cover is cumuliform except at sunrise when morning stratus forms in the forests. Position relative to the wind matters significantly.

Sumatra and Java. Ceilings below 10,000 feet occur most in the afternoon through early evening and least overnight. Ceilings occur 30-40 percent of the time at most places in the afternoon and evening and 15-25 percent of the time the rest of the daylight hours. Overnight, ceilings occur 5-15 percent of the time. A few places in the tropical forests of Sumatra's eastern plain have ceilings below 10,000 feet as much as 70-80 percent of the time during the afternoon through early evening hours and 50-60 percent of the time the rest of the day even though the area is leeward to southwest monsoon flow. This is because of the tremendous amount of moisture available locally. The cloud cover is mainly stratocumulus and cumulus clouds with rainshowers embedded. The smaller islands that surround Sumatra and Java have less cloud cover, especially overnight. Ceilings occur 20-30 percent of the time in the afternoons and early evenings and only 5-10 percent of the time the rest of the day.

Ceilings below 3,000 feet occur at rates only slightly lower than ceilings below 10,000 feet. Ceilings occur 25-35 percent of the time during the afternoon through early evening hours and 10-20 percent of the time the rest of the daylight hours. Overnight, ceilings occur 5-10 percent of the time. A few places in the tropical forests of Sumatra's eastern plain have ceilings below 3,000 feet as much as 65-75 percent of the time during the afternoon through early evening hours and 40-50 percent of the time the rest of the day even though the area is leeward to southwest monsoon flow. Cloud cover is almost exclusively stratocumulus and cumulus with rainshowers embedded. The smaller islands around Sumatra and Java have less cloud cover. Ceilings occur 15-25 percent of the time during the afternoon through early evening hours and 5-10 percent of the time the rest of the day. Overnight ceilings drop under 5 percent of the time on the very small islands.

Ceilings below 1,000 feet occur even less than they did during the northeast monsoon. Except with convection, they almost never occur. Java and Sumatra get them in the higher elevations when cloud cloaks the slopes above 3,000-4,000 feet (900-1200 meters). At lower elevations, ceilings below 1,000 feet will occur briefly with rainshowers or thunderstorms. Sunrise tropical forest stratus may form temporary ceilings at treetop level over tropical forests and marshes, but they burn off with an hour of sunup. Places like Rengat, in the eastern plain of Sumatra, have ceilings below 1,000 feet 10-15 percent of the time at sunrise and under 5 percent of the time the rest of the day. There are a few places in the marshy eastern plain of Sumata that have ceilings below 1,000 feet at much as 25-30 percent of the time at sunrise and 5-10 percent of the time the rest of the day. Only places in the tropical forests and on windward mountain slopes get ceilings below 500 feet. They occur at any time of the day at mountain slope locations. In tropical forests, they occur only at sunrise.

The Lesser Sundas. Ceilings below 10,000 feet occur at different rates at windward and leeward locations. Windward sites get ceilings below 10,000 feet 25-35 percent of the time during the day and 5-15 percent of the time from mid-evening to sunrise. A few places, like Ampenan on Lombok, have ceilings below 10,000 feet 50 percent of the time in the afternoon to early evening hours and 10-20 percent of the time the rest of the day. The terrain is the greatest factor in this. These places get sea breeze clouds because they are on a coast and have volcanic mountains close behind them that pile up convective clouds right over them. Outside of those locations, ceilings below 10,000 feet occur under 5 percent of the time most of the day and up to 15-20 percent of the in the afternoon to early evening hours. The cloud type is cumulus and stratocumulus with isolated towering cumulus. Thunderstorms occur but are widely dispersed.

Ceilings below 3,000 feet occur at only slightly lower rates than ceilings below 10,000 feet. The maximum rate occurs at windward locations on/near the coast with a mountain close behind, 30-40 percent of the time. Elsewhere, ceilings below 3,000 feet occur 20-30 percent of the time in the afternoon to early evening hours and under 5 percent of the time the rest of the day. There are a few leeward locations, like Komoro on Timor and Mali on Alor, that almost never experience ceilings below 3,000 feet. Ceilings below 1,000 feet occur only with convection. Ceilings below 500 feet do not occur except with convection on the windward slopes of mountains.

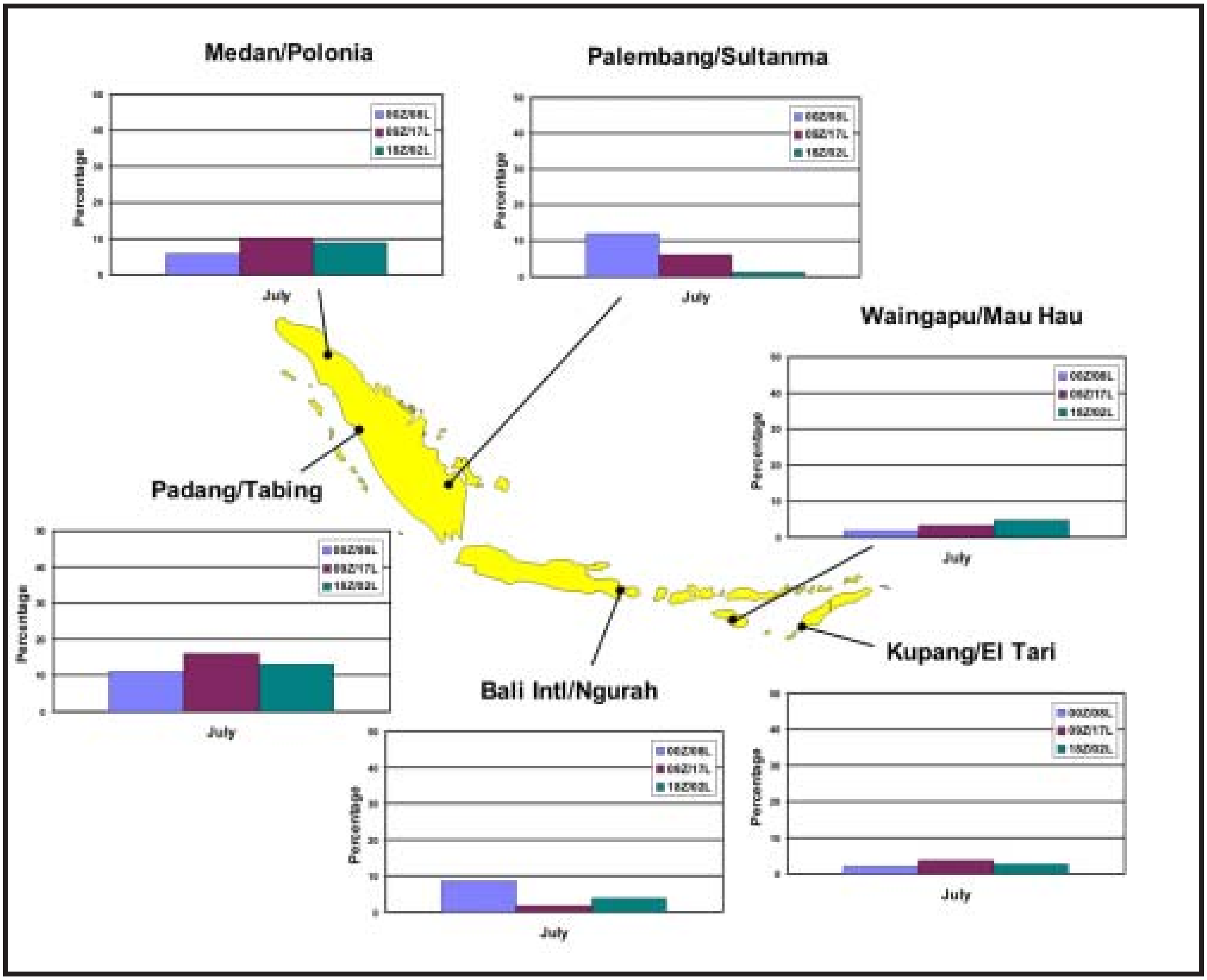

Figure 3-11. Southwest Monsoon Season Percent Frequency of Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Visibility is restricted the most by haze, smoke, and pollution. Rains occur less, especially in the Lesser Sundas, so the air is not cleared as it would be in the northeast monsoon. In El Niño years, the rains are severely restricted, which makes the air quality very bad. Visibility can remain below 3 miles (4,800 meters) for weeks at a time throughout the islands under El Niño conditions. Sumatra and Java, the largest islands in the group, typically suffer the most. See Figure 3-12 for rates of visibility below 3 miles (4,800 meters).

Sumatra. Visibility below 4,800 meters occurs more on Sumatra than any of the other islands. At windward locations, visibility is below 4,800 meters 35-45 percent of the time around sunrise and 15-20 percent of the time in the hours just prior to and just after sunrise. Between 0900 and 0300L, visibility is below 4,800 meters just 3-8 percent of the time. In the tropical forests of the Sumatran eastern plain, there are places surrounded by rivers and marshy ground that have visibility below 4,800 meters 65-75 percent of the time right around sunrise, 25-35 percent of the time in the hours just prior to and just after sunrise, and 5-10 percent of the time the rest of the day (0900-0300L). Visibility below 1 mile (1,600 meters) does not occur outside of thunderstorms or rainshowers at leeward sites. Even at windward sites, occurrence rates are low. Visibility below 1600 meters occurs 3-8 percent of the time at sunrise and not at all the rest of the day. The exceptions are some locations in the tropical forests of the Sumatran eastern plain, such as Rengat/Japura and Palembang. Those places have visibility below 1,600 meters 25-35 percent of the time at sunrise, 15-25 percent of the time just before (0300-0500L) and just after (0700-0900L) sunrise, and under 5 percent of the time the rest of the day. Visibility below 1/2 mile (800 meters) only occurs on the eastern plain in the tropical forests at sunrise. Then, visibility falls below 800 meters 5-15 percent of the time. Conditions rapidly improve once the sun is well up and visibility below 800 meters does not occur the rest of the day outside of rainshower or thunderstorm activity.

Java and the Lesser Sunda Islands. From Bali to Timor, visibility below 4,800 meters does not occur outside of heavy rainshowers and thunderstorms. Java has visibility below 4,800 meters 5 percent of the time at sunrise but not at any time of the day. Rainshowers and thunderstorms only drop visibility for short periods.

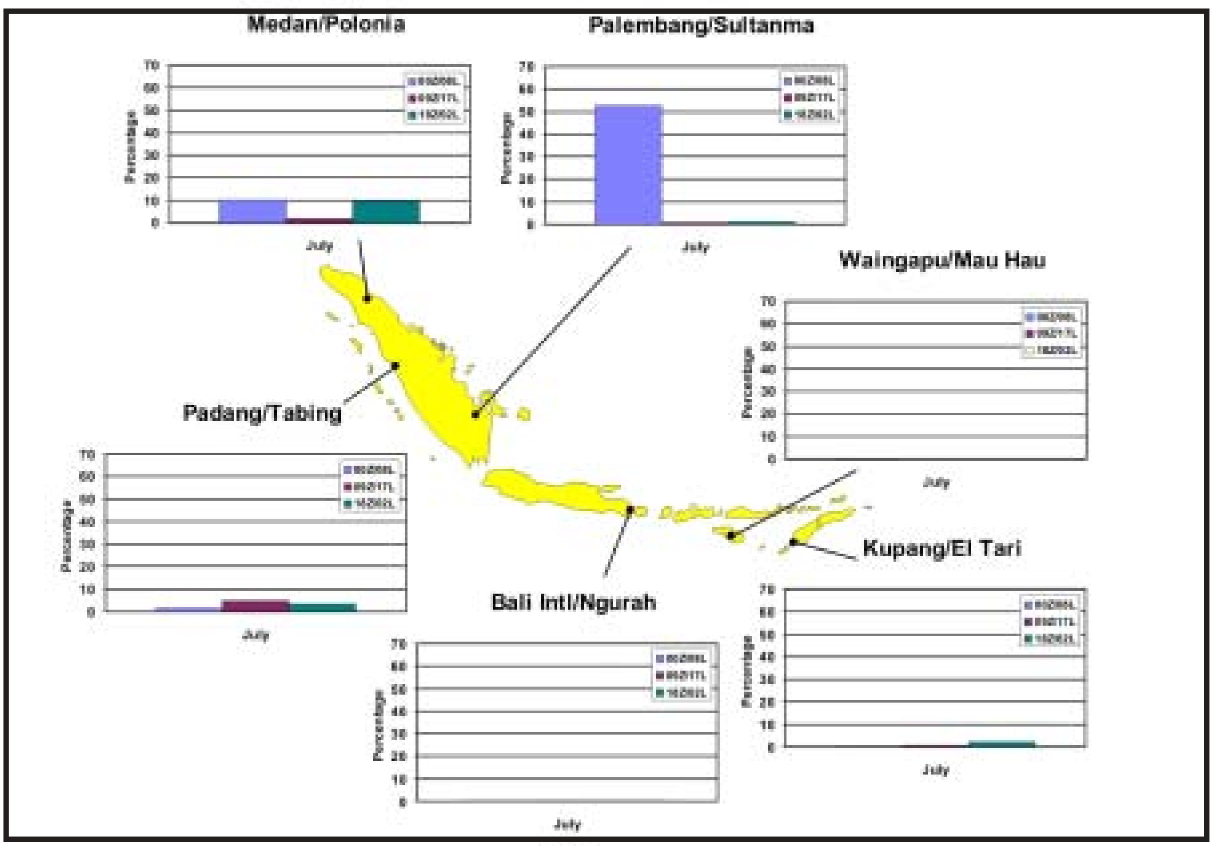

Figure 3-12. Southwest Monsoon Season Percent Frequency of Visibility below 3 Miles (4,800 Meters) for May to October. The graphs show a monthly breakdown of the percent of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Onshore winds associated with the monsoon (south and east coast) augment the sea breeze in the afternoon and often cancel out the night land breeze. Mean wind speeds are generally low, only 3-5 knots most of the time. Wind direction varies widely with terrain, but overall wind flow in windward locations comes primarily from the south (southeast to southwest). Leeward sites have winds determined almost entirely by terrain. Mountain breezes on the south coast are weakened by the monsoon, but the mountain breezes on the north side of the mountains are intensified. This is the period when the north sides of the islands get foehn winds, hot, dry winds that blow 2-3 times stronger than the usual mountain breeze. Record wind speeds are generally associated with easterly waves or tropical cyclones that brush past to the south. Record winds on the south side of the islands tend to be higher (because of the tropical storms), around 95 knots. On the north shores, the records tend to be lower, 65-75 knots (with easterly waves) Figure 3-13 shows wind roses for locations sprinkled throughout the islands.

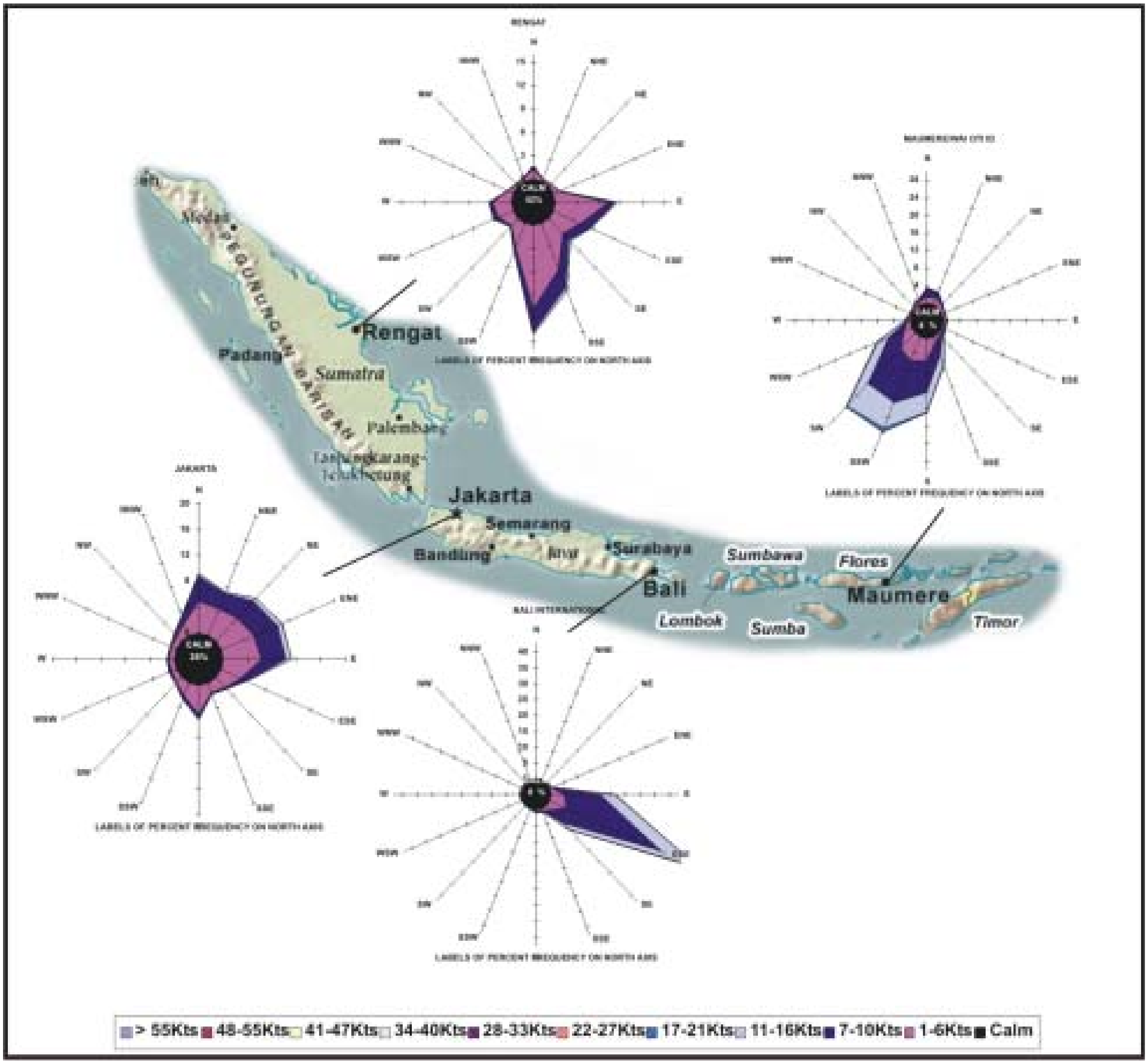

Figure 3-13. July Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Air Winds. This area is overlain by three wind systems. The lowest is the monsoon flow. The southwest monsoon wind system is 6,000-10,000 feet deep south of the equator and around 15,000 feet north of the equator. The southwest monsoon tends to be more easterly south of the equator and more westerly north of the equator. Between the monsoon flow and the tropopause, tropical easterlies dominate. Above the tropical easterlies (above the tropopause), layers of persistent easterlies alternate with persistent westerlies. The layers slowly sink toward the tropopause and dissipate, so there is a steady oscillation (over a 2 year period) between easterlies and westerlies at the top of the tropopause. Speeds typically average 10-15 knots at low levels, do not exceed 35 knots even at 300 mb, and reach 45 knots at 150 mb. See Figure 3-14 for upper-air wind roses for selected locations.

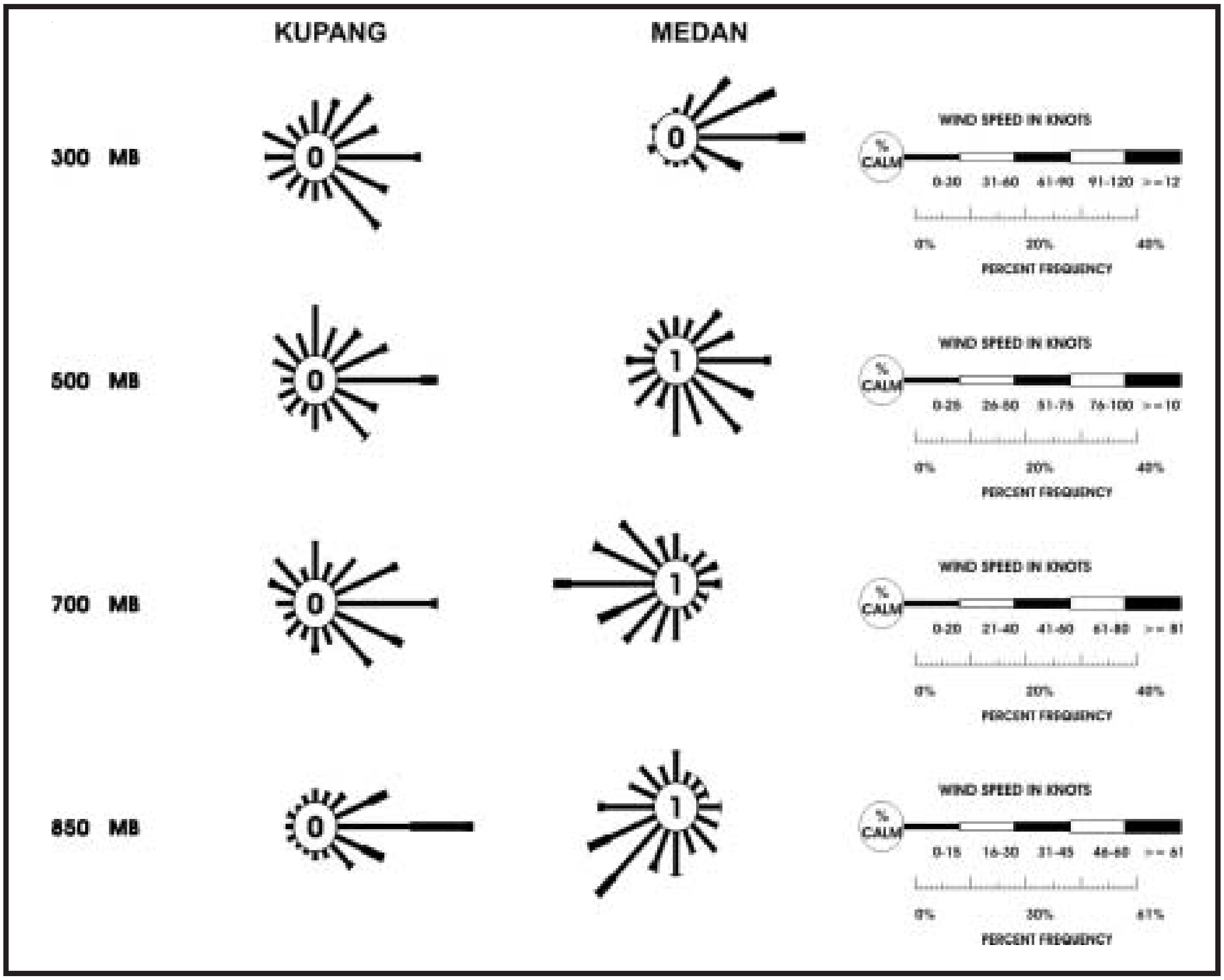

Figure 3-14. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb for selected locations.

Precipitation. This dry season is driest in the Lesser Sundas and wettest on Sumatra and western Java. The SIOT lies over the west end of Java (oriented N-S) and contributes to convection on Java and Sumatra, especially the south coast of Sumatra. East of those two islands, the other islands are under a ridge of high pressure east of the SIOT. Most of the precipitation comes from rainshowers. Figure 3-15 shows precipitation amounts in the dry season. Figure 3-16 shows the number of rain, thunderstorm and hail days.

Sumatra and Java. Sumatra and Java do not have a true dry season, only one that is drier than the wet season. On the north side of Sumatra and Java, 6-8 inches (150-200 mm) of rain falls in May and October. In June-September, rainfall is less, 4-6 inches (100-150 mm) per month. On the south side of the two islands, the rainfall amounts are higher. There, the mean rainfall is 8-10 inches (200-250 mm) per month in May and September. In June-August, rainfall is 6-8 inches (150-200 mm), but in October, it rises sharply to 14-16 inches (350-400 mm) as the NETWC moves over the area.

There are paces on the Sumatra southern coast that regularly have 3-4 inches (75-100 mm) more rain than the average because of terrain features They share in common proximity to the windward coast and high mountains close behind them. This area stretches from Sibolga to Padang. High in the mountains, rains of 12-18 inches (300-450 mm) per month are normal. On both islands, the places at the highest elevations, like Lebongtandai on Sumatra, record up to 30 inches (750 mm) of rain in a single month.

Sumatra has more rain days than Java. Leeward sites on Sumatra average 10-15 days per month with the most days in May and October and the fewest in June and July. Windward sites on Sumatra have 15-20 days with rain. The most occur in May and October and the fewest in June-August. On Java, windward sites have 8-12 days with rain. The most occur in May and October (October is slightly higher than May), and the fewest days occur in June and July. Leeward sites have 5-10 rain days with the maximum in May and October and the minimum in June and July. On both islands, high mountain windard locations get rain daily.

Thunderstorms occur mos in May and October, 5-10 days, and taper down to the minimum number of days by July, 3-8 days. A few places get more frequentthunderstorms, up to 15 days in May. These are caused by nocturnal thunderstorms that move down from the mountains. Thunderstorm activity occurs daily in the high mountains on windward slopes.

The Lesser Sundas. On the Lesser Sundas, conditions are drier than on Sumatra and Java. The farther east an island is in the chain, the drier the climate in the southwest monsoon. From Bali to Timor, precipitation amounts drop to half those of April, to an average of 1-3 inches (25-75 mm) per month in May. In June through October, accumulations are even lower, an average of 0.25-2 inches (5-50 mm) per month. The exception is the northeastern coast of Timor, which is in easterly wind flow and has southeast-facing mountains practically right to the coast. There, precipitation amounts stay higher later into the southwest monsoon, 5-9 inches (125-230 mm) in Ma, 4-7 inches (100-175 mm) in June, 1-3 inches (25-75 mm) in July, and under 0.5 inch (10 mm) in August through October. Precipitation drops sharply when the monsoon is strongest and overrides the easterly flow.

The most rain occurs in May and early June and the least from July to October. In May, the Lesser Sundas get 3-6 days with rain. In June, the average drops to 2-5 days and by July, most places drop to 1 day or less with rain. A few places in the mountains on windward slopes see much more rain than average. Viqueque, in the northeastern coastal mountains of Timor, gets as many as 16 days of rain in May, drops to 10-12 days in June and July, and then falls to 1-4 for August-October. Thunderstorms occur most in May and October, during the transition periods between monsoon regimes, but still occur only 3-5 days in those months. At the height of the southwest monsoon season, thunderstorms commonly occur less than 1 day a month from June to September at most locations.

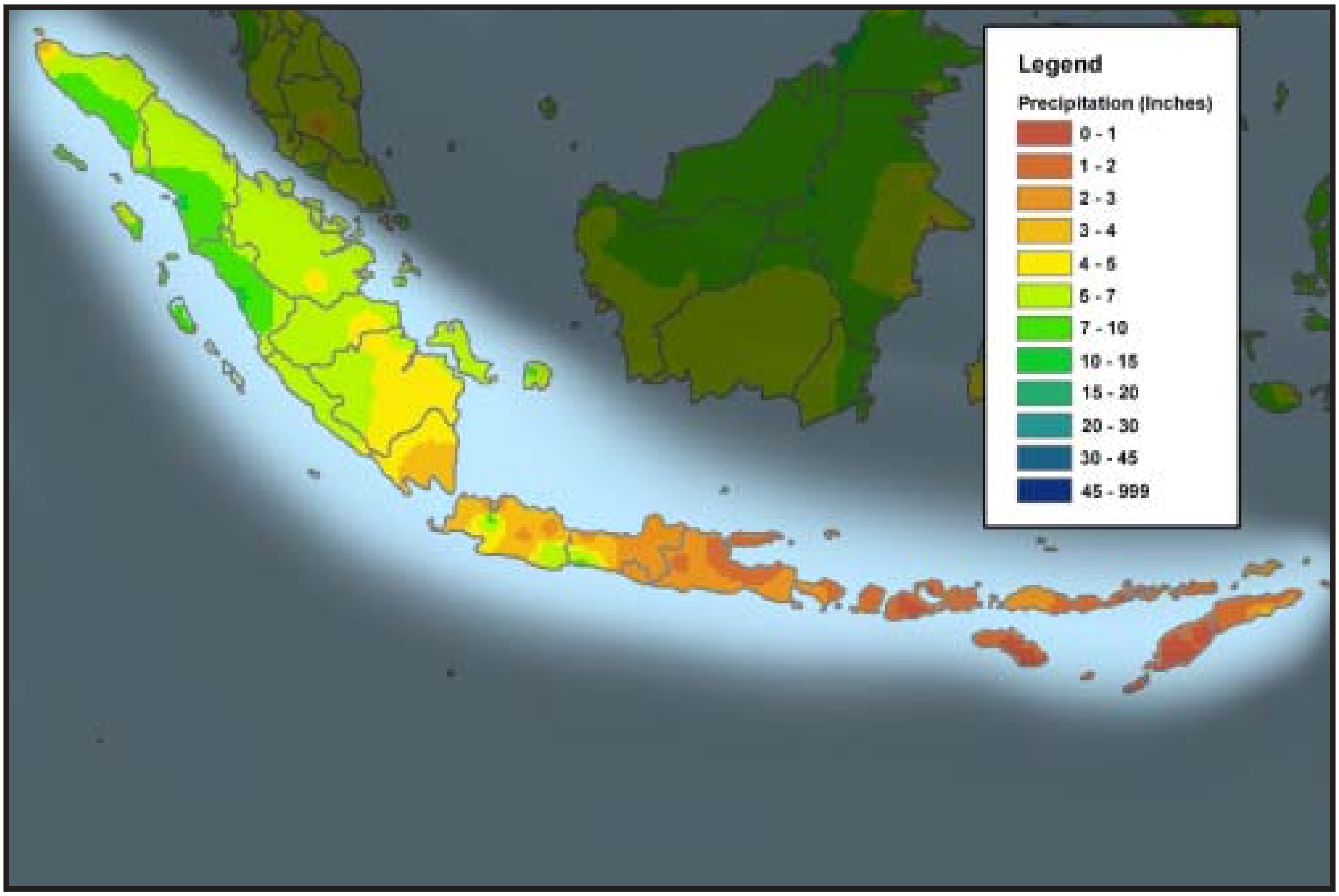

Figure 3-15. July Mean Precipitation. The figure shows mean precipitation in the region.

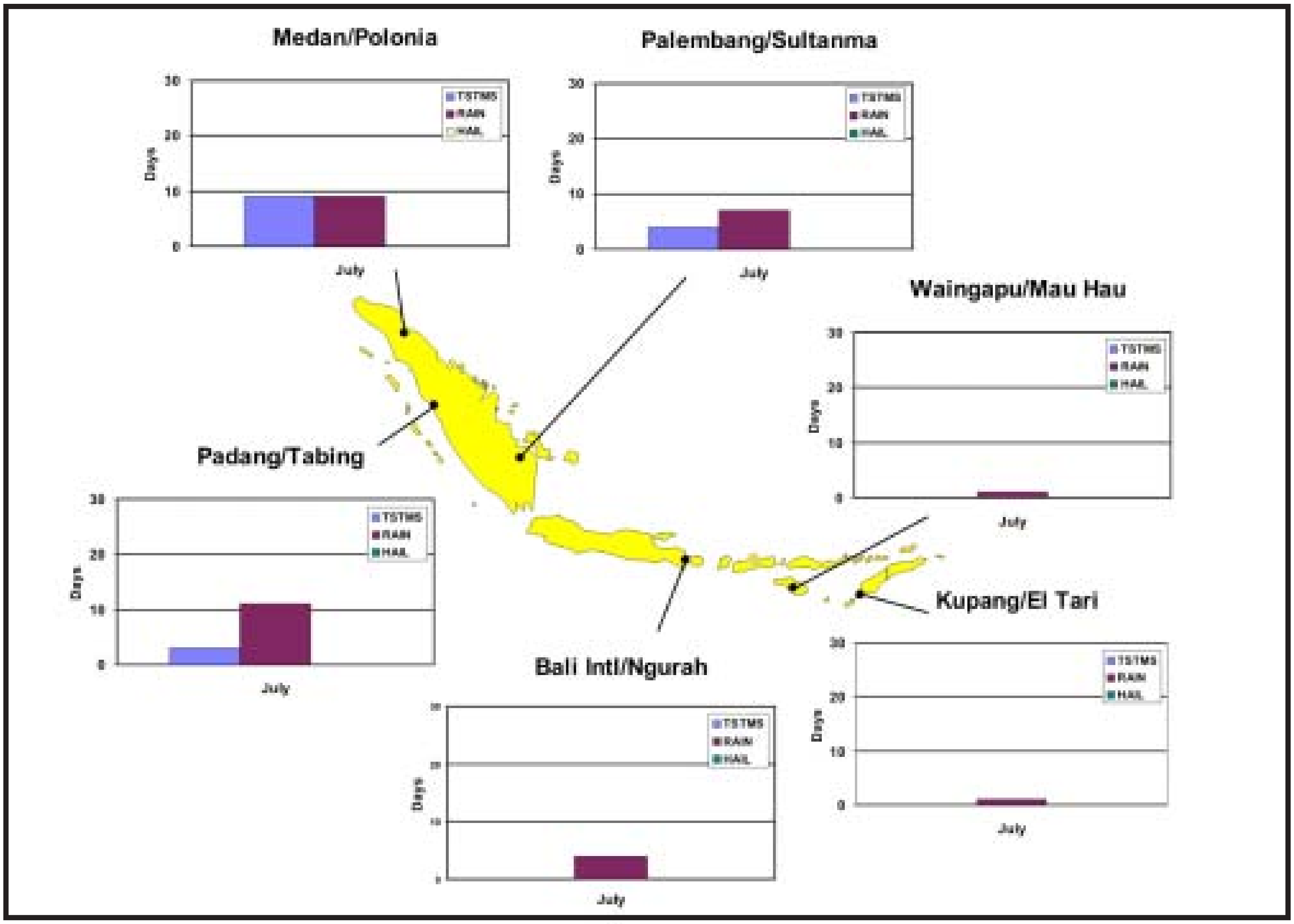

Figure 3-16. Southwest Monsoon Mean Precipitation and Thunderstorm Days, from May to October. The graphs show the average seasonal occurrences of rain, thunderstorm, and hail days for representative locations in the region.

Temperatures. Temperatures vary more diurnally and with elevation above sea level than with season. Mean highs consistently range between 84° and 88°F (29° and 31°C) from May to October. Most places are at 86°F (30°C). The mean lows are 73° to 77°F (23° to 25°C) with most places around 75°F (24°C). Temperatures cool moist adiabatically with elevation, roughly 3 Fahrenheit degrees per 1,000 feet (1.65 Celsius degrees per 300 meters). Places under windward flow have more cloud and are cooler than those places on the leeward side of the mountains.

Leeward sites generally have the highest extreme maximum temperatures. Throughout the islands, temperatures rise above 95°F (35°C) from less than 1 up to 3 days all season. The average is higher on the smaller islands, especially those with low mountain features or nothing but low terrain. Extreme highs range from 101° to 112°F (38° to 45°C). The highest extremes occur at leeward sites with foehn winds. See figure 3-3 for foehn wind locations. Most places vulnerable to foehn average only 1-3 days with foehn winds per year. Jatiwangi, on Java, gets a mean of 7 days with foehn per year, 4-6 days occur in the southeast monsoon. The maximum occurrences are in September and October. The extreme lows range from 59° to 68°F (15° to 20°C) with most sites around 64°F (18°C). See Figures 3-17 and 3-18 for the mean maximum and minimum temperatures for representative locations on the islands.

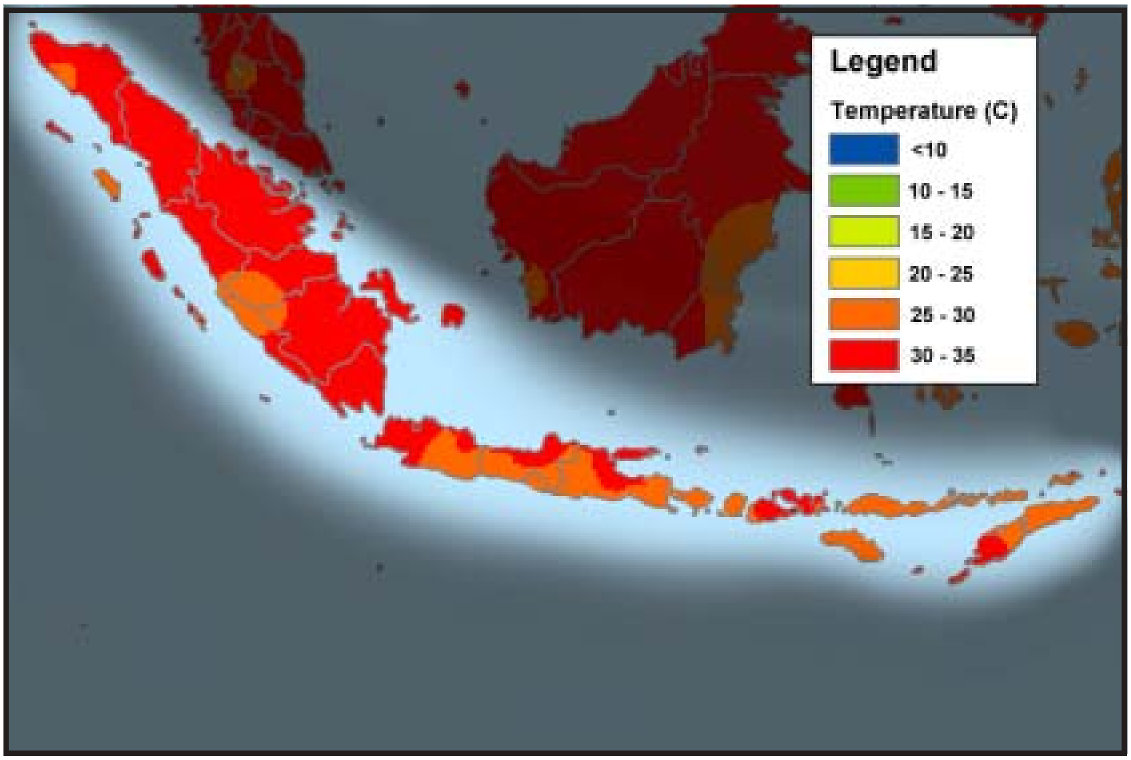

Figure 3-17. July Mean Maximum Temperatures Mean maximum temperatures represent the average of all high temperatures for a representative month of the southwest monsoon season. Daily high temperatures are often higher than the mean.

Figure 3-18. July Mean Minimum Temperatures. Mean minimum temperatures represent the average of all low temperatures for a representative month of the southwest monsoon season. Daily low temperatures are often lower than the mean.

Hazards. Tropical cyclones, easterly waves, thunderstorms, foehns and torrential rains are the main hazards. Tropical cyclones are not a serious threat, however, some occasionally pass close enough to the southern coasts to bring widespread, heavy rains. If a tropical disturbance is developed enough when it passes through the Timor and Arafura seas, it can also bring high surf and strong winds. Java and Sumatra are less vulnerable, but can still get rain and wind from a storm far enough north to brush them. The season for tropical cyclones is normally June to November, but early storms are not unknown. Tropical cyclones typically track south of the islands, but a few come close enough to raise winds and drop torrential rains on the islands. The southern sides of the islands tend to be most vulnerable to damage. Easterly waves that track across the South China Sea occasionally drop heavy rains and stir up high winds for the islands. The north sides of the islands tend to be most vulerable to damage.

Thunderstorms reach 35,000-45,000 feet with a few tops above 50,000 feet. Cells produce heavy rains, moderate-to-severe in-cloud turbulence, and powerful downrush winds. Hail is generally small and soft and does little damage. Icing in cloud is confined to the upper reaches of the cloud, where the temperature falls below 32°F (0°C). Foehn winds are most common during the southwest monsoon. They occur on the lee sides of the islands, especially on Sumatra and Java. These winds can cause structural damage or trigger fires. Torrential rains, which can produce flooding, occur regularly. The windward slopes of mountains get the most precipitation and have the highest single rain event totals as well. The massive amount of water that drains into the lowlands at the feet of the mountains causes rivers to rise above their banks very quickly. In marshy areas, the extra water is quickly dispersed, but farms can suffer losses. Also, the swiftly flowing water itself can be dangerous as it washes away roads and bridges, and cases mud slides. The danger is greatest where forests have been clear cut or slash and burn farming techniques have stripped vegetation from the soil. Reconvergent thunderstorms form downwind of mountain features. They produce heavy rains, down rush gusts and on rare occasions soft hail.

Trafficability. On the western islands, rainfall amounts drop, but travel conditions are little changed; marshy areas are still wet, and mountainous areas are still open to mudslides and flooding when it rains. Rainfall is less on the north sides of the western islands because they are on the lee of the mountains during the southwest monsoon, but it rises in windward areas, especially on the south end of Sumatra and the western half of Java. On the eastern islands, rainfall drops significantly and conditions become dry and dusty.

Chapter 4

BORNEO

This chapter describes the geography, major climatic controls, special climatic features, and seasonal weather for Borneo. The northern and western portions are occupied by East Malaysia, the independent state of Brunei, and the Indonesian islands of Anambas and Natuna. The southern and eastern portions are occupied by Kalimantan (a part of the Republic of Indonesia). The subregions discussed in this chapter are the northern coastal region, the central highlands, the southern lowland, and the Anambas and Natuna islands, as shown below.

Figure 4-1. Borneo. The figure shows the location of Borneo in relation to other countries in the western Pacific region.

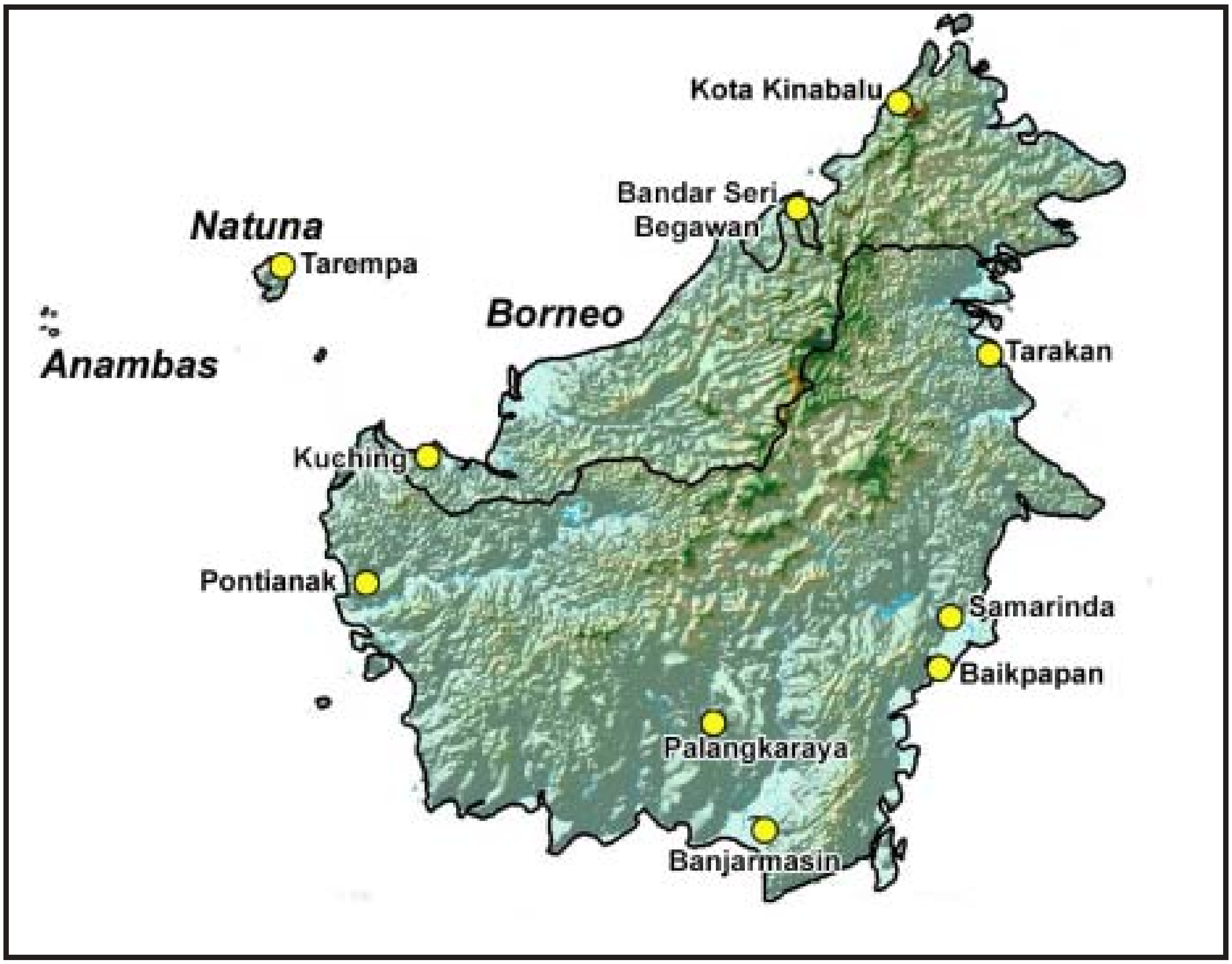

Figure 4-2. Topography of Borneo.

TOPOGRAPHY. Borneo is in the Malay Archipelago. This mountainous, forested island is shared by the following three nations: East Malaysia, Brunei and Kalimantan. Borneo is bounded to the northwest by the South China Sea, to the northeast by the Sulu Sea, to the east by the Celebes Sea, to the southeast by the Makassar Strait, to the south by the Java Sea and to the southwest by the Karimata Strait. The islands of Anambas and Natuna, west of Borneo, are included in this region.

Major Terrain Features.

Northern Coastal Region. The belt of land along the coast is mainly low and swampy. Borneo has indented coastlines with numerous good harbors. The northern coastal region is a narrow, discontinuous, lowland that covers the coasts of East Malaysia and Brunei. The strip is 5-60 miles (8-100 km) wide and is divided into two segments: the northwest and northeast coasts.

The swampy northwest coast is hilly from the Malaysia/Kalimantan western border to the Lupar River, 45 miles east of Kuching. Several small mountains rise to near 3,000 feet (900 meters). From the Lupar River to Bintulu, the region flattens and is widest, 60 miles (100 km), near Sibu. Most hills are under 500 feet (150 meters), although a few small mountains rise to near 2,000 feet (600 meters) 20 miles (32 km) southwest of Bintulu. This marshy, forested section is bordered to the southeast by the foothills of the Upper Kapuas and Hose Mountains. From Bintulu to Brunei, the strip narrows to about 40 miles (64 km) with 500-1,000-foot (150-300-meter) hills.

Brunei consists of two areas separated by the Limbang River valley. Inland areas of the west are sparsely forested rolling hills that seldom rise over 1,000 feet (300 meters). In the east, the Crocker foothills rise to over 3,000 feet (900 meters) in the extreme south. A rolling alluvial plain, interrupted by foothills and mountain spurs, makes up the rest of the northwest coast (north of Brunei). This narrow strip is 5-10 miles (8-16 km) wide, although it widens to 25 miles (40 km) on the peninsula that juts out between Brunei and Kimanis Bays. The foothills of the Crocker Range reach elevations over 2,000 feet (600 meters) 5-10 miles (5-8 km) inland, where the central highlands begin. Isolated hills, with elevations of 500-1,000 feet (150-300 meters), are on some of the small islands near the coast. The flat swampy island of Beruit, near Sibu, is the largest.

The northeast coast includes the Borneo coast that meets the Sulu and Celebes Seas. Malaysia's northeast coast begins with two large, marshy peninsulas separated by Marudu Bay. The eastern peninsula has numerous hills, generally under 1,000 feet (300 meters) in the north and 1,000-2,500 feet (300-750 meters) in the south. The western peninsula is mostly flat in the north and hilly in the south, with elevations near 2,500 feet (750 meters). Several hilly offshore islands are also included in this section; the largest is Banggi Island. Between Labuk and Lahad Datu Bay (also called Darvel Bay) a swampy lowland is 30-50 miles (50-80 km) wide. It has a rolling terrain with scattered hills and ridges, backed by the rugged central highlands. Some small mountains rise to near 2,100 feet (640 meters) 10 miles (16 km just south of the Labuk River. The Bagahak Range is 20 miles (40 km) east of the river. The region is bordered to the west by the foothills of the Crocker and Meliau Ranges, before it turns east-southeast toward the eastern foothills of the Brassey Range to the Malaysia/Kalimantan border.

The peninsula between Lahad Datu Bay and Tawau Harbor has scattered hills and mountains. The region is 10-30 miles (16-48 km) wide south of the border. A flat, swampy, coastal plain is 5-10 miles (8-16 km) inland of the eastern border to the Kayan River. Numerous hills, some exceeding 3,000 feet (900 meters) in elevation, line the western plain. Marsh covers most of the northeast coast and usually extends no more than 10 miles (16 km) inland. Swampy conditions continue well inland around rivers, especially along the Kinabatangan River, about 15 miles (24 km) south of Sandakan Harbor.

Central Highlands. This region primarily consists of high, rugged, densely forested mountains and hills that cover much of Borneo. The primary ranges extend northeast to southwest and include the Crocker, Muller, Kapuas and Schwaner Mountains. The central highlands are discussed in two segments: the northern and southern highlands.

The northern highlands cover the mountainous terrain north of about 1°N. The foothills of the Upper Kapuas in the west are east of Lupar River. As the ridgeline meanders towards Brunei to the northeast, the highlands are continued by the Iran and Tamu Ranges. A few peaks exceed 6,000 feet (1,800 meters) along this stretch. Among the highest are the Hose Mountains, which rise to over 6,600 feet (2,000 meters). Smaller, parallel ranges within 40 to 60 miles (64 to 96 km) of the coast mark the northern extent of the highlands. North and east of Brunei, the highlands follow the Crocker Range. This range begins 5-10 miles (8-16 km) inland along the northwest slopes, where elevations regularly reach 2,000 feet (600 meters). The Crocker Range parallels the northwest coast and extends 15-25 miles (24-40 km) inland. Most peaks are under 6,000 feet (1,800 meters), however, Mount Kinabalu, is 13,455 feet (4,101 meters) high. The smaller Brassey Mountains, oriented west-southwest to east-northeast, lie 30 miles (48 km) inland of the northeast coast between Darvel and Sebuku Bays. Most peaks average 3,000-5,000 feet (900-1,500 meters). Numerous large mountains are near the eastern end of the international border and extend southward to just north of the equator. A few peaks exceed 8,000 feet (2,400 meters).

The southern highlands include the mountains south of about 1°N. The Muller Range extends north-south through central Borneo. The average height is 4,500 feet (1,370 meters), with a peak elevation of 7,350 feet (2,241 meters). The Muller Range extends southwest across the equator, and merges into the Schwaner Range, with a maximum elevation of 7,474 feet (2,280 meters). Scattered mountains, with elevations below 4,000 feet (1,200 meters), are between the Kapuas River and the Schwaner Range. The highest peak is Mount Saran at 5,768 feet (1,758 meters).

Southern Lowlands. This is an area of swamps interrupted by a few valley plains and small mountain ranges. It is divided into three segments, the southeast, the south-central, and the southwest lowlands.

The southeast covers all lowland areas adjacent to Makassar Strait and westward to the mouth of the Barito River. The region begins at Point Mangkalihat and includes the southern slopes of the Mangkalihat Range. The lowlands widen to 90 miles (144 km) from Sangkulirang Bay to the equator. South of the equator, the lowlands include most of southeast Borneo. Marshes prevail along the immediate coast and around rivers. The southeastern lowlands are bounded to the west by the Kusan and Kulling mountain ranges, two long chains of northeast-southwest oriented mountains. This stretch of single mountains and ranges is 30-50 miles (48-80 km) wide and has several peaks over 4,000 feet (1,200 meters) tall. This includes Mount Besar at 6,237 feet (1,892 meters). From west of these mountains to the Barito River, the lowlands are rolling hills with isolated mountains mainly under 2,500 feet (750 meters). The southeast is bordered by rising highlands to the northwest and Barito River to the west. Several small, marshy islands lie off the immediate coast. The largest, Laut Island, is 60 miles (96 km) long.

The south-central lowlands begin at Barito River and extend west to Karimata Strait. This section is bordered to the northwest by foothills of the Schwaner Mountains. Vast swamps dominate the coasts and as much as 100 miles (160 km) inland along many of the south-draining rivers. Elevations in this forested plain are generally under 1,000 feet (300 meters). Between the relatively flat plain and northwestern portions of the bordering highlands, an irregular zone of hill country with isolated mountains sometimes reaches heights of up to 2,500 feet (750 meters).

The southwest lowlands begin at the Karimata Strait and extend north to the western Malaysia/Kalimantan border. This section is backed to the southeast through east by the foothills of the Schwaner and Muller Ranges. South of the equator, a flat, marshy plain is dotted with a few small isolated mountains. This section is 30-60 miles (48-96 km) wide and is bordered to the east by mountains with peaks of 2,500-4,500 feet (750-1,400 meters). The region widens considerably north of the equator and includes most of Kapuas River. Its northern border is the western international borderline and the foothills of the Upper Kapuas Mountains. Several large mountains are just south of the borderline. A few small islands lie off the immediate southwest coast.

Anambas and Natuna Islands. The Natuna Islands are a small group 150 miles (250 km) northwest of the westernmost tip of Borneo. The group consists of one main island, Natuna Besar, and several much smaller islands within 10 miles (16 km) of the west coast of the main island. Natuna Besar is 45 miles (70 km) long and 30 miles (50 km) wide. Natuna Besar is forested and has only a few small mountains. The highest peak on the island is Mt. Ranai, at 3,396 feet (1,035 meters). There is a small chain of hills along the southern tip of the island that is 1,500-2,000 feet (450-600 meters) in height. A few of the smaller islands have central hills of 1,000-1,500 feet (300-450 meters).

The Anambas Islands are a smaller group 120 miles (200 km) west-southwest of the Natuna Islands. The largest, Jemaja Island, is 16 miles (27 km) long and 10 miles (16 km) wide. Jemaja is covered by small, rolling hills that line the 3 main peninsulas. The highest hill on the island is 1,540 feet (469 meters) high and is in the center of the northeastern peninsula. There are only two other islands in the group more than 5 miles (8 km) long. Siantan Island is 12 miles (20 km) long and

6 miles (10 km) wide, and Matak Island is 11 miles (17 km) long and 5 miles (8 km) wide.

Rivers, Lakes, and Drainage Systems. Many rivers, most navigable, drain Borneo. The most important are the Rajang, Barito, Kapuas and Mahakam Rivers. The chief river of western East Malaysia, is the 350 mile (560 km) long Rajang River. The Rajang River is navigable for about 80 miles (130 km) and passes through Sibu. This wide-delta river drains into the South China Sea. The 400 mile (640 km) long Mahakam River is in eastern Kalimantan. This river rises in the mountains of central Borneo and flows east-southeast to the Makassar Strait. About 100 miles (160 km) from its mouth, the river is joined in a region of marsh and lakes by the Belajan and Telen Rivers. The Barito River, in southeastern Borneo, is 550 miles (880 km) long. It rises in the central Muller Mountains and flows south to the Java Sea. The lower course flows through a marsh where cross branches connect with other streams. The Kapuas River is in western Kalimantan. This 450 mile (720 km) long river rises into the mountains of north central Borneo and flows west into the South China Sea.

Borneo has several large lakes, but none are in East Malaysia or Brunei. Several large lakes are near Mahakam River in eastern Kalimantan. Lake Djempang, Lake Melintang and Lake Semajang are among the largest in this region. The huge Riam-Kanan reservoir is in a valley just north of the Kusan Range in the southeast lowlands. Beladjau Lake is in the south central lowlands near Pembuang River. Several rather large lakes lie just north of the Kapuas River in the southwest lowlands. Among the largest are the Luar, Genali and Pengembung Lakes.

MAJOR CLIMATIC CONTROLS

Asiatic High. This strong, thermal anticyclone controls the weather over much of Asia from October to April. The Asiatic high works with the Aleutian low to create a strong northeasterly pressure gradient over the western Pacific Ocean. This northeasterly air flow combines with the northeast trade winds from the North Pacific high to control the position of the NETWC during the northeast monsoon season. Strong cold surges from the Asiatic high force the NETWC south of the equator. During periodic lulls in the Asiatic high, the NETWC temporarily moves northward, to just south of Borneo, and brings periods of convective activity to the southern coasts.

North Pacific High. The position of the high is linked to the movement of the NETWC and to oscillations in convection. Between September and November, this high retreats southward over the warm South China Sea and western Pacific, and allows tropical disturbances to develop well into Northern Hemisphere winter. During the northeast monsoon, it initiates the northeast trade winds that dominate flow. An area of convergence forms in the South China Sea between flow from the Asiatic high and the northeast trades. The warm waters along the northwest coast of Borneo make it a prime area for convective activity in the convergence zone. Additionally, the northeast trades keep the windward parts of the island rainy during the northeast monsoon, despite lulls in the flow from the Asiatic high.

Australian High. This thermal high is present during Southern Hemisphere winter and is a key component of the southwest monsoon. The outflow from the Australian high combines with the southeast trades from the South Pacific high to regulate the position of the NETWC. These southeasterly winds turn southwesterly once across the equator. The high is strongest in July, with a mean central pressure of about 1,022 mb. It is neither as strong nor as persistent as the Asiatic high, and is regularly crossed by disturbances and migratory highs.

South Pacific High. This Southern Hemisphere anticyclone displays an oscillation similar to its Northern Hemisphere counterpart and plays a small part in the southwest monsoon over Borneo. The South Pacific high has a much greater impact on the position of the NETWC east of Borneo. During Southern Hemisphere winter, the high creates the southeast trade winds that, combined with outflow from the Australian high, move the NETWC. Periodically, the South Pacific high oscillates and creates ripples (easterly waves) along the NETWC. Borneo is most apt to feel the effect of easterly waves early and late in the southwest monsoon. As the high retreats poleward, the effects of the southeast trades are diminished, and the NETWC moves southward across Borneo. The mean seasonal positions of the South Pacific high are in Figures 2-4a through 2-4d.

South Indian Ocean (Mascarene) High. This feature plays a major role in the southwest monsoon. The cross-equatorial circulation from this high augments outflow from the Australian high to move the NETWC northward through Borneo in April and May. As the South Pacific high retreats eastward to its Southern Hemisphere summer position near 30° S 87° E, the cross-equatorial flow is diminished and the NETWC moves southward through Borneo in October and November.

Asiatic Low. This thermal low anchors the western end of the NETWC. It is strongest in July, when its central pressure averages 994 mb. Fluctuations in the position and strength of the Asiatic low cause oscillations and waves along the NETWC. As the Asiatic low weakens and fills in late summer, the NETWC moves south through Borneo.

Australian Low. This thermal low strengthens the pressure gradient between Asia and Australia during the northeast monsoon season. The Australian low is present in Southern Hemisphere summer and is strongest in January. Early in the northeast monsoon season, the NETWC is primarily driven by the Asiatic high. By January however, the intense Australian low keeps the NETWC over southern Indonesia. An exceptionally strong Australian low tends to pull the NETWC farther south to between Java and northern Australia. Conversely, during periods of exceptionally weak Australian lows, the NETWC fluctuates north of its mean position, and affects the southern shores of Borneo. This rare occurrence usually only happens when the Asiatic high is also weakened.

Near Equatorial Trade Wind Convergence (NETWC). The NETWC is a convergence zone of the outflows from the North Pacific and South Pacific highs. As the air streams converge in the equatorial low-pressure region, intensified convective cloud masses occur along a line or band, which is sometimes semi-continuous convergence boundary. Sudden violent weather is associated with an active NETWC. The NETWC most greatly affects Borneo during the monsoon season transition months (April-May and October-November).

South Indian Ocean Trough (SIOT). During Southern Hemisphere winter, an induced trough develops as a result of the confluence of the outflows between the South Indian Ocean high and the Australian high. The trough normally extends from just off the coast of northwestern Australia to the southwestern tip of Borneo. The existence and strength of the trough is dependent upon the strength of the Australian high. When the Australian high is at its strongest, convection increases along the trough and brings thunderstorms to southwestern Borneo. The Australian high is often disrupted by transitory systems and migratory highs. During these periods, the Australian high weakens and occasionally disappears, and the induced trough weakens and disappears with it. This causes a lull in convective activity across southwestern Borneo. At the end of Southern Hemisphere winter, when the Australian high disappears, the SIOT vanishes.

Easterly Waves. Easterly waves (also known as equatorial waves) are troughs or cyclonic curvature maximas that move westward in the trade-wind easterlies. They are characterized by lower pressure on the equatorward side and a amplitude maximum in the low to mid levels of the atmosphere, usually best seen at 850-700 mb. The most common type of wave, the stable wave, moves slower than the prevailing low level flow. Weather is typically excellent ahead of the wave and deteriorates once the trough axis passes. Neutral waves move with the low-level flow and have a near-vertical axis. The worst weather associated with the neutral wave is concentrated at the trough axis. Unstable waves move faster than the low-level flow.

The worst weather associated with an unstable wave occurs ahead of the trough axis. Conditions rapidly improve once the trough axis passes. Easterly waves typically travel 400 miles (640 km) per day and are more active when close to the NETWC. Most waves originate either from upper-level, cold-core lows or from the equatorward extension of a mid-latitude trough. Because easterly waves form and travel on the poleward side of the NETWC, and because Borneo straddles the equator, easterly waves commonly affect Borneo in the late stages of either monsoon season and during the transitions when the NETWC is close to Borneo.

Monsoonal Breaks. During the southwest monsoon, buffer cells periodically form in cross-equatorial flow near Borneo. They drift north of the equator, form equatorial anticyclones, disrupt monsoonal flow and cause monsoon breaks. During the breaks, gradient-level southwesterlies are frequently replaced by weak easterlies over Borneo. At full strength, the anticyclone merges with the North Pacific high as a ridge at 500 mb. Branches of the NETWC develop on either side of the equator. Disturbances along each branch cause an overall increase in precipitation in the equatorial western Pacific basin. These disturbances bring short, but intense rain spells to Borneo. The break ends when a mid-latitude trough moves southward and shifts the subtropical ridge eastward.

Latitudinal and Oceanic Influences. Borneo is bisected by the equator and is surrounded by warm tropical waters. As a result, the mean position of the NETWC lags slightly behind the seasonal path of the sun. Since the sun is overhead at the vernal and autumnal equinoxes, the times just past these events closely coincide with when the NETWC moves through Borneo between monsoons. Just past the summer and winter solstice is when the southwest and northeast monsoons are at full force and farthest from Borneo. Sea-surface temperatures are fairly stable all year, generally between 80° and 85°F (27° and 29°C). These warm waters feed the monsoonal flow and moderate the climate. The average diurnal temperature range is actually greater than the mean annual temperature variation range.

El Niño. During an El Niño episode, the water temperatures near Borneo are typically 4-6 Fahrenheit (2-3 Celsius) degrees cooler than normal. This cooler water inhibits convection over the region and causes much drier conditions to persist. During exceptionally strong El Niño occurrences, Borneo has severe droughts. El Niño effects are first felt in Borneo during the late northeast monsoon season and have the greatest impact during the southwest monsoon that follows. El Niño usually limits the amount and intensity of cold surges through the next northeast monsoon season. Since only the strongest cold surges reach Borneo, convection that does occur (albeit erratically), is stronger than usual.

La Niña. In a La Niña, conditions are the opposite of those with an El Niño. Above normal sea-surface temperatures increase precipitation across Borneo. La Niña is an integral part of the El Niño/ENSO cycle and often follows an El Niño. The drought conditions of an El Niño episode cause a decrease in vegetation. Fires that are rampant in the parched landscape also clear the island of much of its greenery. The above normal precipitation associated with a La Niña frequently causes severe flooding and landslides.

Buffer Cells. Buffer cells form in cross-equatorial flow and have weak circulation. Circulation is either cyclonic or anticyclonic (depends on the season). During the southwest monsoon, the circulation is clockwise. In the northeast monsoon, the circulation is weakly counterclockwise. Buffer cells are initiated by a surge in the monsoonal flow that creates a weak eddy in the cross-equatorial flow. These cells usually only last about 3-4 days and are normally only present during surges in the monsoonal flow. Buffer cells usually straddle the equator, so there is no net confluence or difluence noted. Occasionally, buffer cells drift far enough north to form an equatorial anticyclone. Buffers cells that become equatorial anticyclones are the main cause of monsoonal breaks.

SPECIAL CLIMATIC FEATURES

Mesoscale Convective Complexes (MCCs). MCCs are common off the northwest coast of Borneo all year. They produce heavy rain and hail. MCCs that affect Borneo begin during the late evening when convective cells or cloud clusters interact with the land breeze. A few form when convective cells interact with NETWC. Precipitation evolves into a continuous mesoscale rain area that is a combination of deep cells and stratiform rain. A late morning or afternoon sea breeze cuts off low-level convergence and cell formation off the coast. The sea breeze may still induce cell formation of a much smaller scale near the coastline. Figure 2-55 shows a model of a typical MCC off the coast of Borneo.

Convergence Zones. Convergence zones develop between prevailing synoptic flow and diurnal circulations, particularly off the east coast of Borneo. They are most frequent at night when the nocturnal outflow of cool air from the mountains reaches the seas during periods of light wind and relatively clear skies. The cool air lifts the prevailing airstream and initiates lines of cumulus clouds. These lines often develop into thunderstorms by daybreak but dissipate by mid-morning.

Barat. This is a squall that occurs from December to February, primarily along the eastern coast of East Malaysia. This strong, west or northwest wind is usually associated with a tropical depression that moves westward from the southern Philippines. Barats occur any time of the day and are most intense along the windward coast. Considerable cloudiness and heavy precipitation accompany this squall.

Foehns. These hot, dry winds are prevalent in the central highlands of Borneo. They occur when air from the monsoonal flow is forced over the mountain tops and descends dry adiabatically. The resultant change in temperature and humidity is dramatic. Occasionally, the foehns are so hot and dry, crops on the leeward slopes are withered or destroyed.

General Weather. The Asiatic high is firmly established and continues to strengthen over the rapidly cooling continent. The Australian thermal low intensifies. High pressure prevails over the North and South Pacific Oceans and the Indian Ocean. The Australian low intensifies and enhances flow from both the Asiatic and North Pacific highs. The contraction and southward migration of the subtropical ridge in the western Pacific allows the NETWC to move southward into northern Borneo. The NETWC tracks southward across Borneo during the late year transitional period, from mid-October to mid-December. This allows air masses from the Asiatic high and North Pacific high to penetrate south of the equator and establish Borneo's northeast monsoon.

November normally begins with the NETWC moving south over Borneo's central highlands. Portions of the southern lowlands may still be under the influence of the southwest monsoon. During the northeast monsoon, the NETWC sometimes becomes active as weak disturbances move along it. An active NETWC brings heavy and continuous rain. These disturbances can become coupled with east-moving disturbances along the subtropical jet and create broad areas of rainy weather. Widespread convergence usually brings heavy cloudiness, showers and thunderstorms, whereas weak, nearly parallel flow may result in only light cumulus buildup with scattered showers. Interior stations not exposed to the monsoons may receive their maximum rainfall during this transitional period.

The northeast trades dominate the northeast monsoon between cold surges from the Asiatic high. A deep upper trough in the midlatitudes often triggers intense anticyclogenesis over central China and cyclogenesis over the East China Sea. As the pressure gradient across the east China coast tightens, cold air bursts out of the continent across Taiwan towards northern Borneo and a cold surge is initiated. Cold surges occur every 5-20 days during the northeast monsoon season. They are most common in December and January, when four a month reach the equatorial South China Sea. As the cold surge moves out of the source region and over the ocean, the original continental polar air modifies into maritime tropical air before it reaches Borneo. These surges converge with the northeast trades to enhance the low-level northeasterly wind flow. The terrain in the western Pacific Basin helps turn this northeasterly flow cyclonically and forms an area of convergence. These quasi-stationary cyclonic circulations are intensified by the convectively unstable wind surges. They bring heavy rain to Borneo's northern coast, particularly on the windward mountain slopes. By mid-December, the NETWC usually moves south of Borneo.

The northeast monsoon has a pronounced effect on Borneo's climate as it grows in strength through February. This large-scale northeasterly airstream becomes northwesterly over southern Borneo as it crosses the equator. Borneo's mountains cause drastic regional variations in weather, especially in precipitation. Maximum precipitation occurs along the windward coast and mountain slopes.

The northeast monsoon subsides from March to May as the Asiatic high weakens then disappears. The increase in solar insolation across the rapidly warming continent causes the Asiatic thermal low to form. During this transitional period, the overall circulation across Asia shifts from anticyclonic to cyclonic. The NETWC moves gradually northward in 1-3 day shifts. Northward shifts usually move the NETWC 50-60 miles (90-100 km) during each surge. In April, the Australian thermal low is replaced by a developing anticyclone over southern Australia. Cold surges weaken and become more variable; early signs of southwest monsoonal flow occur. The western Pacific subtropical ridge expands and tracks northward and allows the NETWC to move irregularly northward into southern Borneo. Adverse weather returns with its late season advance into the central highlands. Portions of northern Borneo are normally still under the influence of the weakening northeast monsoon. The convergence zone moves northward across the island during the transition period of mid-March to mid-May.

Sky Cover.

Northern Coastal Region. The mean monthly total cloudiness during the northeast monsoon across the northern coastal region is 75-85 percent. Ceilings below 3,000 feet are most common on the extreme western promontory of the northwest coast, the area most perpendicular to the prevailing northeasterly flow. Kuching records low ceilings 50-60 percent of the time in the afternoon (Figure 4-3). Peak occurrence is normally at mid-season, when monsoonal flow is at its strongest. Elsewhere along the northwest coast, the occurrence is lower, only 10-30 percent of the time, as the monsoonal flow is more parallel to the coastline. After sunset, cumulus and cumulonimbus clouds flatten and dissipate. Radiational cooling often creates sheets of thin stratus after midnight through mid-morning over swamps and sometimes on the lower mountain slopes.

Central Highlands. Cumulus clouds form soon after sunrise on windward slopes. Monsoon flow against mountains produces continual cloud banks on the windward slopes and over most peaks. Air brought in by sea breezes thickens cloud banks and produces towering cumulus or cumulonimbus on the slopes. Clouds may cloak ridges above 3,000 feet. Low ceilings are most frequently observed during the afternoon. Convective clouds may remain throughout the night on the windward slopes and ridges. A clearing tendency is common on the lee side of the mountains. Thunderstorms occur most frequently when the NETWC passes over the region. It is during these periods of increased convective activity that Sintang records the highest rate of ceilings below 3,000 feet (roughly 40-60 percent of the time).

Southern Lowlands. Abundant low cloudiness is the norm for this swampy area. Ceilings below 3,000 feet occur 60-80 percent of the afternoon hours, 50-70 percent of the evening hours, and 40-60 percent of the morning hours. Thunderstorms tend to linger into early evening and dissipate overnight. During the transition months, Pangkalanbuun records low ceilings in the afternoon more than 85 percent of the time. In the southwest, ceilings below 3,000 feet occur about 60-80 percent of the afternoon hours. Evening and morning ceilings below 3,000 feet occur about 30-50 percent of the time. Pontianak records low ceilings approximately 75 percent of the time during the transition season when the NETWC is closest. The southeast records a much lower incidence of ceilings below 3,000 feet. Bandjarmasin averages low ceilings 20-30 percent of the time, mostly in the morning and afternoon. Balikpapan records low ceilings much less frequently, more than 15 percent of the time all season.

Anambas and Natuna Islands. Ceilings below 3,000 feet on Natuna Island occur less than 20 percent of the time all season, regardless of the time of day. Thunderstorms occasionally form over Mt. Ranai but rarely over the rest of the flat island. On Anambas Island, Terempa records afternoon ceilings below 3,000 feet more than 50 percent of the time at the height of the season and 30 percent of the time in April. The outer coastal ridges of the main islands frequently have cumulonimbus clouds in the afternoons. Terempa is on the northeastern slope of the ridge that extends along the entire western coast of the island. By April, the wind shifts to southwesterly and low ceilings at Terempa drops to less than 10 percent of the time during the mornings and evenings.

Visibility.

Northern Coastal Region. Rain is the primary restriction to visibility. Less dense, but more frequent restrictions are haze and fog. Heavy rain showers briefly reduce visibility to near zero. The coast reports its poorest visibility in the early morning. Morning fog frequently obscures visibility over the swampy lowlands; however, it is below 3 miles (4,800 meters) for most stations less than 5 percent of time. Kuching records the greatest percent frequency of visibility below 4,800 meters of any station in the region. Upslope fog forms near Kuching between the coast and the Bungo Range approximately 10 percent of the time. Fog and haze occur at Brunei 15-20 days a month during the northeast monsoon. Haze prevails at Sandakan 10-15 days per month; the highest rate is when the NETWC is near.

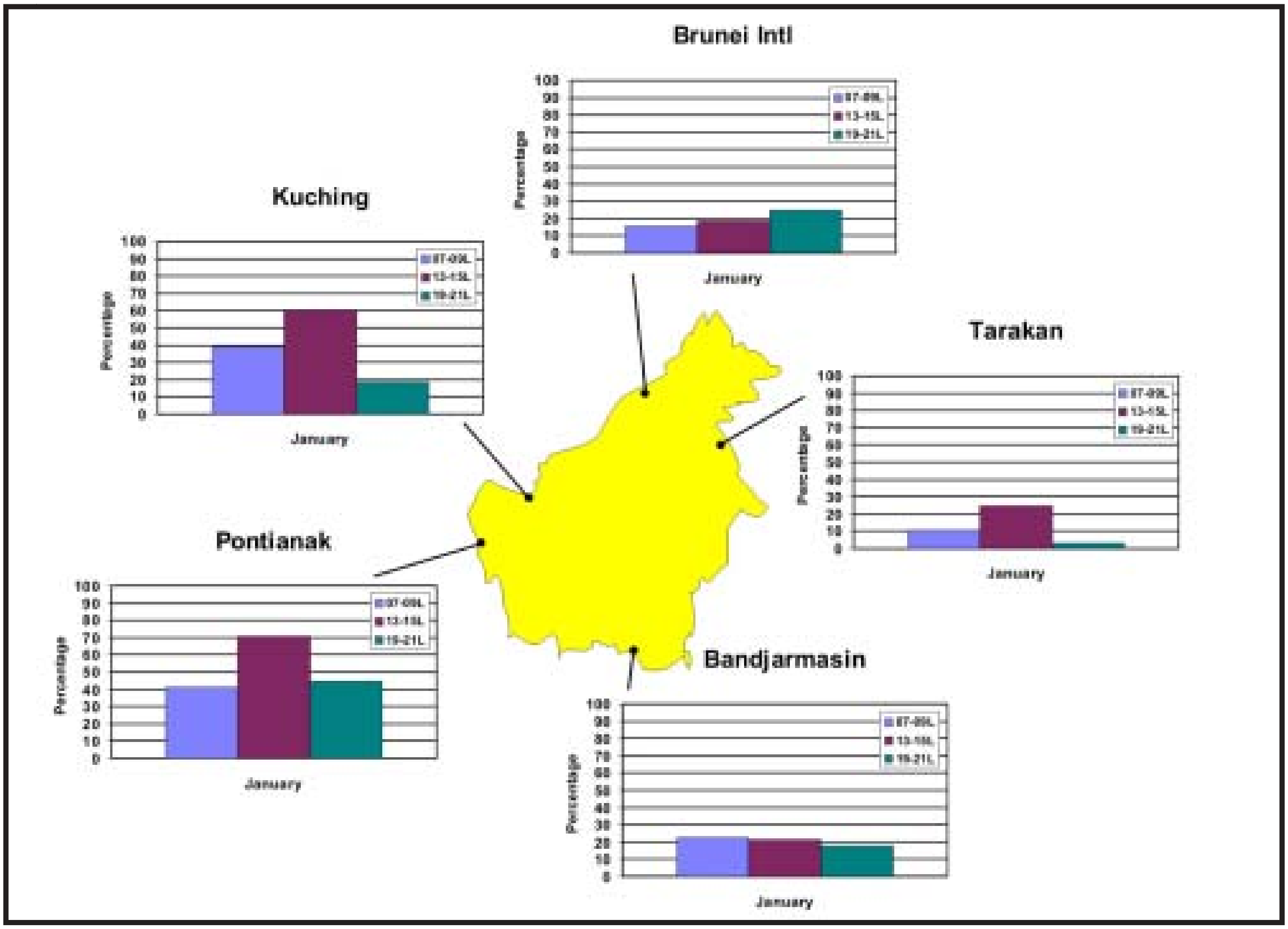

Figure 4-3. Northeast Monsoon Percent Frequency of Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet, based on location and diurnal influences.

Central Highlands. The worst visibility is recorded when the NETWC is near. Fog is most prevalent in the swampy river valleys. Morning fog along the Kapuas River restricts the visibility at Sintang to below 4,800 meters 25 percent of the time in January up to almost 40 percent of the time in March. By early afternoon, the fog dissipates, and the rate drops to below 5 percent of the time. Sintang records about 15 haze days per month. Afternoon convection obscures exposed mountain peaks and ridges. Heavy rainshowers in the mountains briefly restrict visibility to near zero.

Southern Lowlands. Fog occurs 10 days per month. Visibility is restricted to below 4,800 meters at Pontianak 20-46 percent of the mornings. By afternoon, the fog burns off and visibility is restricted less than 5 percent of the time. Pontianak averages almost 15 haze days per month. Pangkalanbuun, on the western edge of the south-central lowlands, records restricted visibility on 30 percent of the mornings per month. This city, near the Kumai River, also averages 12 days with fog and nearly 17 days with haze per month. Farther inland, Panarung has much fewer fog days, but about the same amount of days with haze as Pangkalanbuun. Panarung, at the northern edge of the marshy region that surrounds the Kahajan River lowlands, averages low visibility during the morning hours 15-20 percent of the time. Visibility in the southeastern lowlands is considerably better than at other areas of the lowlands. For the most part, most places have visibility below 4,800 meters less than 5 percent of the time, predominately in the morning. They get less than 3 fog days per month but 15-25 days of haze per month (Figure 4-4).

Anambas and Natuna Islands. Fog is nearly nonexistent in the Anambas and Natuna Islands. Both groups record 10-15 days per month with salt haze. Ranai and Terempa record a late night maximum for visibility restricted to below 4,800 meters of 10-15 percent of the time.

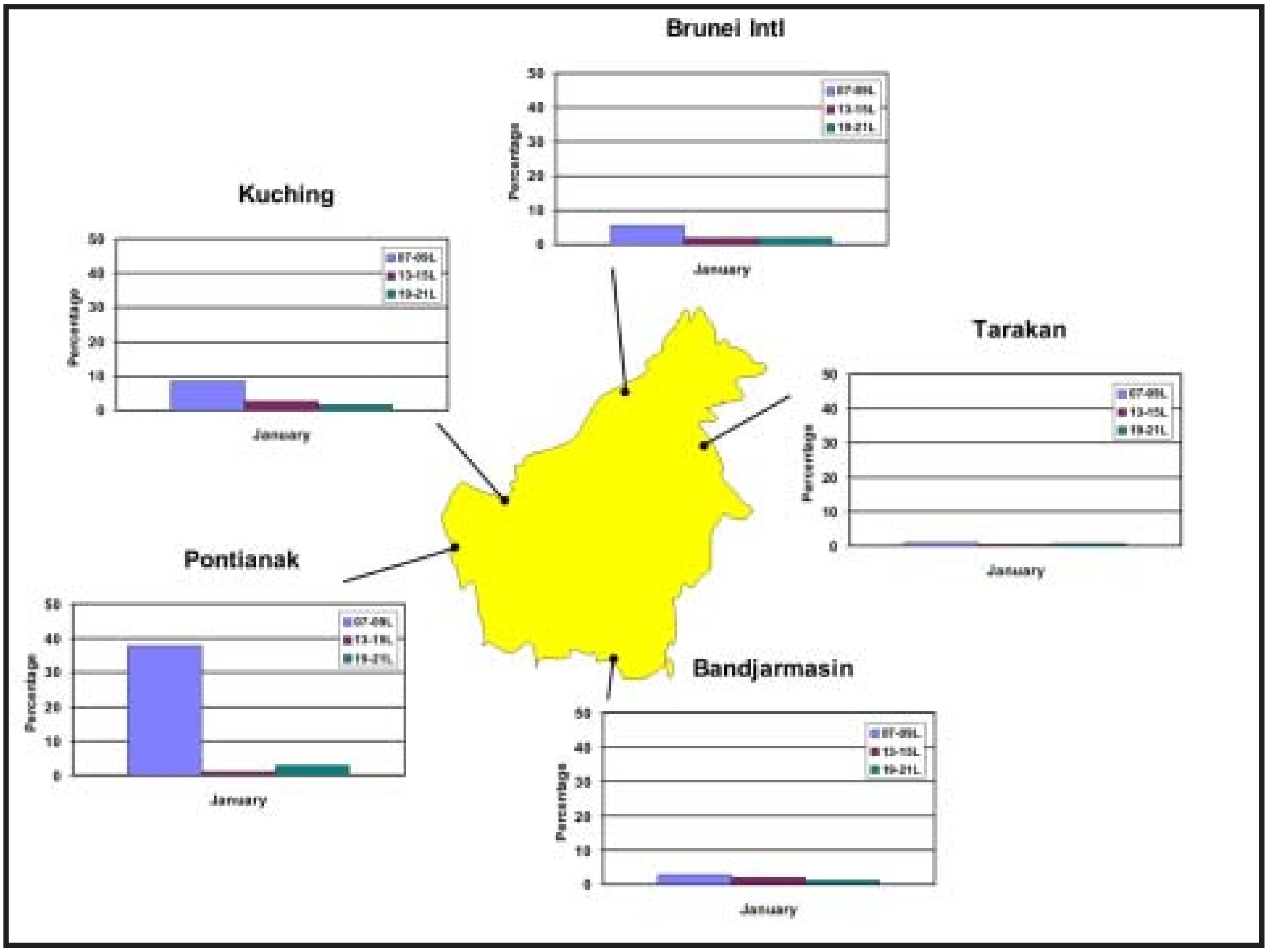

Figure 4-4. Northeast Monsoon Percent Frequency of Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percent of visibility below 4,800 meters, based on location and diurnal influences.

Surface Winds.

Northern Coastal Region. Northeasterlies prevail across the coast from mid-November to mid-April. Topography strongly affects the wind speed and direction, especially during the night, under the radiational inversion. Tarakan, on the northeastern coast, is totally sheltered from northeast monsoon flow. This station experiences calms approximately 90 percent of the time. Several stations undergo a dramatic reversal in wind direction from day to night. Sandakan has a weak, but persistent southwesterly nocturnal mountain/valley breeze approximately 60 percent of the time. After the inversion breaks (by mid-morning), the wind speed increases and shifts direction to northeasterly. At the height of the northeast monsoon

(January), the nocturnal breeze is overridden. The monsoon flow is so dominant, Sandakan records northeasterly nocturnal breezes approximately 35 percent of the time. The day/night reversal is noted at other northern coastal stations. Brunei also experiences a steady, southwesterly nocturnal drainage breeze that is similarly overridden. Wind roses for the northern coast reflect a transition from the southwest monsoon in November and a return to the southwest monsoon in March or April. Wind speeds with the monsoon are strongest in January and February. During the transitions, wind speeds decrease and directions get more variable (Figure 4-5).

Central Highlands. The terrain greatly influences local winds. Winds funneled through the long, narrow valleys and mountain gaps in East Malaysia are commonly accelerated by 35-45 knots during the northeast monsoon. Foehns are common in the central highlands of Borneo. Gradient winds are northeasterly north of the equator and northwesterly in cross-equatorial flow.

Southern Lowlands. From mid-December through mid-March, winds are predominately northwesterly. Coastal stations usually have a weak, nocturnal land breeze and by late morning, the sea breeze usually begins. Pontianak has calms 70-80 percent of the time. The rest of the time, it records a weak, easterly breeze out of the Kapuas-Ketji River valley at night. In the afternoon, the wind reverses and enters the river valley as a 10-15 knot sea breeze. Pangkalanbuun, sheltered from prevailing flow, records calms 70-90 percent of the time. Balikpapan, on the southeastern coast feels the full brunt of the northeast monsoon. At night, Balikpapan observes a weak, but consistent

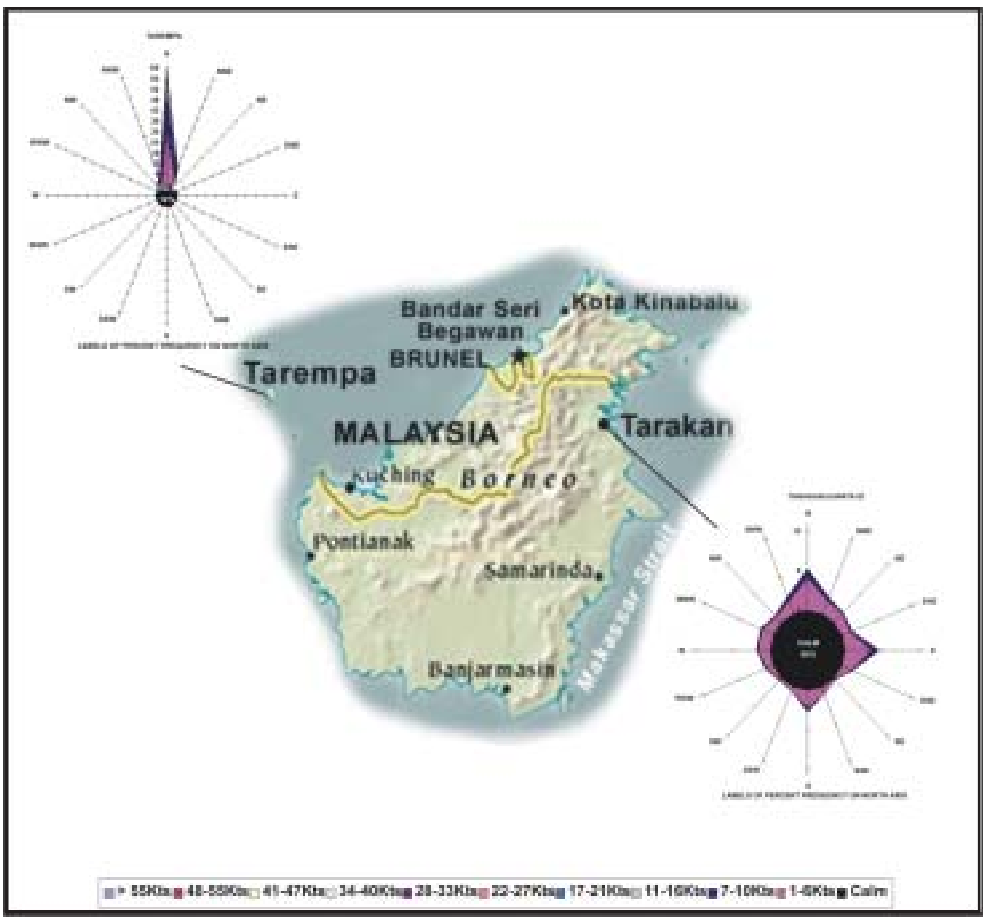

Figure 4-5. January Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds, based on frequency and location.

northwesterly drainage breeze from the mouth of Balikpapan Bay. By late morning, the wind shifts to northeasterly and increases in strength.

Anambas and Natuna Islands. The monsoon is the dominant wind field and overrides all local effects, such as the land/sea breeze and the effects of terrain. The northeast monsoon normally makes its first appearance by November, reaches peak intensity in January, and begins to weaken in March and April. The prevailing wind direction for Terempa and Ranai is almost exclusively northerly from mid-November through mid-April. Wind speeds are usually less than 15 knots, except in January when speeds above 25 knots occur up to 5 percent of the time. These higher winds are with monsoon surges. By April, the prevailing direction is almost evenly split between northerly and southerly as the NETWC fluctuates overhead.

Winds Aloft. In November, the southwest monsoon is still evident below 700 mb; easterlies prevail above 700 mb all year. From December through March, the northeast monsoon dominates at 700 mb and below. Equatorial easterlies prevail in the mid- and upper-levels. Winds rarely exceed 30 knots above 700 mb and only occur at 850 mb and below during monsoonal surges. Equatorial Borneo is never affected by the jet streams of either hemisphere. During an El Niño cycle, the upper-level easterlies are weakened. The El Niño also weakens monsoonal surges and the low- to mid-level easterlies associated with surges. See Figure 4-6 for upper air wind roses at selected locations.

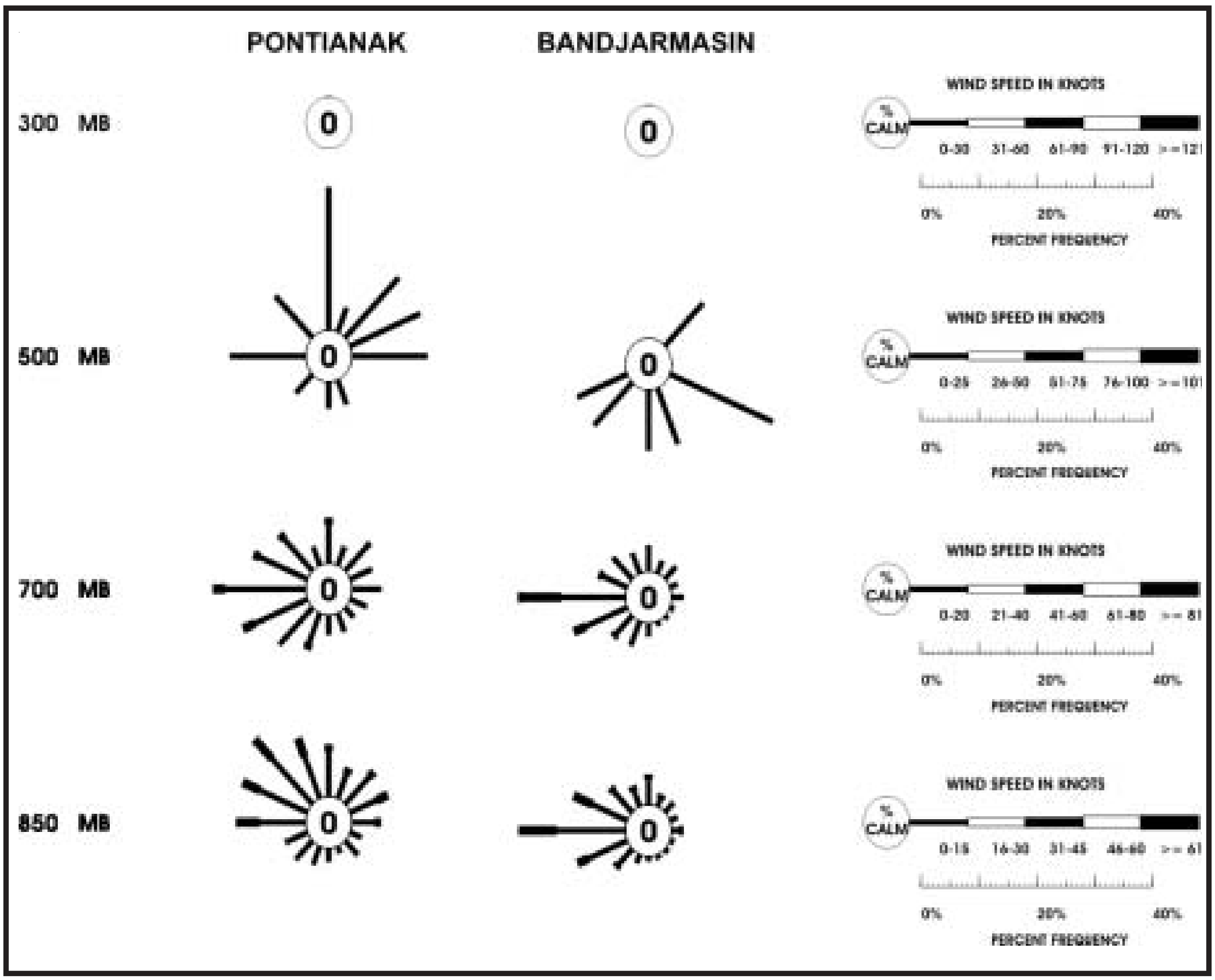

Figure 4-6. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 mb and 300 mb for selected locations.

Precipitation.

Northern Coastal Region. This area receives its greatest rainfall at the height of the northeast monsoon. Terrain determines how much rain each location receives. Rainfall is most plentiful along the windward slopes, especially along the eastern slopes of the Bungo Range, near Kuching, and along the northern and eastern slopes of the Meliau Mountains between Kudat and Sandakan. Kuching averages 26 inches (650 mm) of rain in January, while Kampong Matang, on the eastern slopes of Serapi Mountain, averages almost 34 inches (850 mm). On the northeastern coast, Beluran, a city on the southern coast of Labuk Bay, averages more than 20 inches (500 mm) of rain in January. Stations on the lee side of mountain ranges receive comparatively little rainfall. Tawau, a city on the lee side of the Brassey Mountains and at the mouth of Sibuko Bay, receives less than 5 inches (125 mm) of rain during January. Sites in the lee of the Crocker Range average less than 6 inches (150 mm) of rain during January. See Figure 4-7 and 4-8.

Rain normally falls in brief, heavy rainshowers. Thunderstorms are most common during the afternoon. Over the water, these storms normally occur at night. Thunderstorms occur most frequently in October-November and April-May when the NETWC passes over the area. Monsoonal surges initiate considerable convective activity in northern Borneo. Surges also

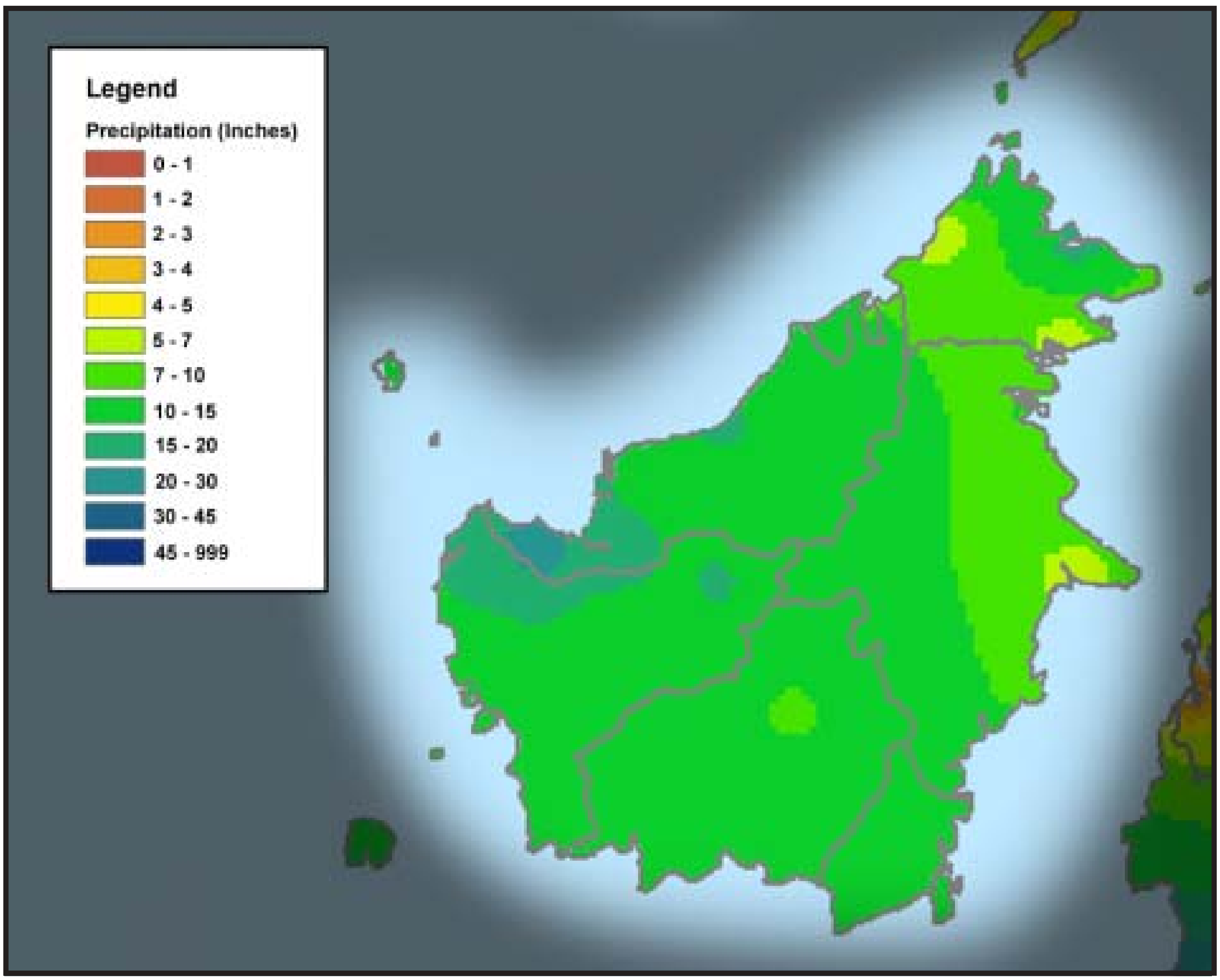

Figure 4-7. January Mean Precipitation. The figure shows precipitation in the region.

establish an east-west pressure gradient in the equatorial South China Sea, which triggers east-moving waves in the NETWC. These waves bring heavy rains to northern Borneo. Barats also occur most frequently at the height of the northeast monsoon season and bring considerable cloudiness and heavy precipitation.

Central Highlands. This area records the annual peak rainfall when the NETWC passes over the area. Interior stations are sheltered from the full impact of either monsoon season, but still receive considerable rain because of orographic lift. Most locations receive 10-14 inches (250-350 mm) of rain at the height of the season (January). During the transitions, the central highlands record 14-20 inches (350-500 mm) of rain. Convection typically occurs earlier in the afternoon over the central mountains than along the coasts. Rainshowers and occasional thunderstorms form over the mountains and move over the plains at peak afternoon heating. Rain usually occurs as brief, torrential downpours but, when associated with the NETWC, can be persistent. When a mountain range is perpendicular to the prevailing monsoon, rains may last days at a time.

Southern Lowlands. Most locations record 9-12 inches (225-300 mm) of rainfall in January. In the southeast lowlands, Sangkulirang receives its greatest mean monthly rainfall in December and January, about 7 inches (175 mm) in each month. This city is on the

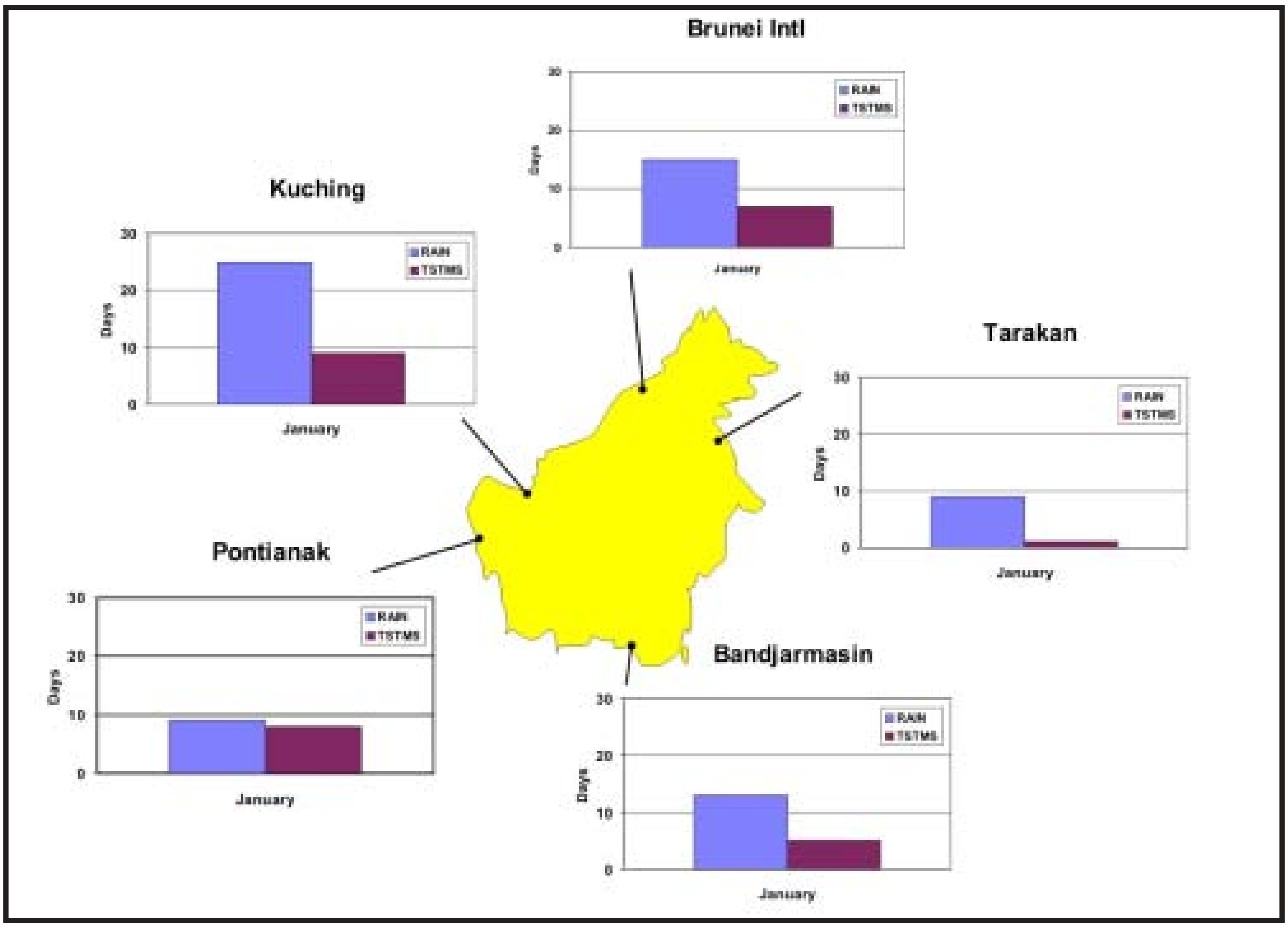

Figure 4-8. Northeast Monsoon Season Mean Rain and Thunderstorm Days for November to April. The graphs show the average seasonal occurrences of rain, thunderstorm, and snow days for representative locations in the region.

lee of the Sambaliung Mountains, near the mouth of the Sangkulirang River. Places south of Sangkulirang, along the coast for about 150 miles (250 km), are in the rainshadow of the Sambaliung Mountains and average less than 6 inches (150 mm) of rain in January. Most of the south-central lowlands receive 12 inches (300 mm) in January. Panhkalanbuun, on the lee of the southern Schwaner Mountains, averages 9 inches (225 mm) of rin at the height of the monsoon, and slightly more, 11 inches (275 mm), in April. Locations not as exposed to the full effects of either monsoon rely on the almost daily rainshowers for precipitation and record only a minor increase with the passage of the NETWC.

Anambas and Natuna Islands. Each island group records a nocturnal precipitation maximum and an annual maximum in November. Terempa, in the Anambas Islands, averages more than 16 inches (400 mm) of rain in November and 12 inches (300 mm) in January. The hilly terrain of Siantan Island assists in the development of convection during the monsoon. At the height of the northeast monsoon, the islands record a sharp drop in total precipitation. From February through April, Terempa averages less than 6 inches (150 mm) of rain each month. As the NETWC moves north across the area at the end of the northeast monsoon there is only a slight increase in precipitation. This is because Terempa is on the lee side (eastern slopes) of the western coastal ridgeline and is shielded from the approaching southwest monsoon. The Natuna Islands record much less precipitation than the Anambas Islands because they are not as hilly.

Temperatures. Temperatures are very warm and are usually accompanied by high humidity. The temperature cools moist adiabatically with elevation. Diurnal variations in mean temperatures exceed annual changes, particularly in the central highlands. Temperature is also a function of cloud cover. Areas under thick clouds do not heat as quickly as those areas not covered. Once the clouds pass or dissipate, the ground quickly heats under the intense sun.

Northern Coastal Region. Temperatures in the higher elevations are normally 3 °F (5.5 °C) degrees cooler every 1,000 feet. Since the temperature at the top of the mountains cools moist-adiabatically and is nearly always saturated, the absolute range between means and extremes is smaller than for sea-level stations. The coolest temperatures are recorded at the highest parts of the Crocker Mountains. Mt Kinabalu, at 13,455 feet (4,104 meters), records temperatures 35-40 °F (19-23 °C) degrees cooler than the temperatures at sea level. During cold surges, the freezing level drops to about 10,000 feet, and on rare occasions, to 8,000 feet. The top of Mt. Kinabalu get snow through most of the northeast monsoon.

The section of the northern coast parallel to the mean flow of the northeast monsoon has the least cloudiness and the highest temperatures. The areas prone to foehn winds record the warmest extreme highs. The lee of the Bungo Range and parts of the coast north of Brunei in the lee of the Crocker Mountains are most susceptible to these winds. The range of mean high and mean low temperatures at coastal stations is narrow. Most stations record a mean high of 86° to 91°F (30° to 33°C) and a mean low of 72° to 75°F (22° to 24°C). Extreme highs for most locations are 96° to 101°F (36° to 39°C) with extreme lows near 60°F (16°C).

Central Highlands. At elevations near 5,000 feet, mean temperatures are 15°F (8°C) cooler than at sea level. Near 8,000 feet, temperatures means and extremes are 24 °F (13°C) degrees cooler. Cloud cover cools the highlands. Most of the central ridges are covered by clouds through a majority of the season. If a ridgeline is not perpendicular to the monsoonal flow, then interior valleys have only scattered cloudiness and much more heating. Mean highs in the highlands are 72° to 78°F (22° to 26°C) at 5,000 feet and about 63° to 70°F (17° to 22°C) at 8,000 feet. Mean lows are 56° to 62°F (13° to 17°C) at 5,000 feet and 48° to 52°F (9° to 11°C) at 8,000 feet. The western highlands, near the Kapuas River, are most prone to foehns and record the hottest extreme highs; temperatures occasionally exceed 100°F (38°C). At the other extreme, during intensely strong cold surges, the freezing level drops to 8,000 feet or slightly lower.

Southern Lowlands. Across the mainly flat southern lowlands, there is a strong maritime influence on mean and extreme temperatures. Mean highs average 85° to 88°F (29° to 31°C), while mean lows average near 73°F (23°C). Several locations have recorded extreme highs near 100°F (38°C). Extremely hot temperatures occur when cloudiness is at a minimum and when offshore flow prevails. Extreme lows are 58° to 62°F (15° to 17°C) and usually only drop below 65°F (18°C) during extremely strong cold surges. See Figures 4-9 and 4-10.

Anambas and Natuna Islands. The air temperature closely follows the sea-surface temperature and closely correlate with the position of the sun. The mean highs range from 84°F (29°C) in January to 90°F (32°C) in April. Mean lows average 75°F (24°C) all season. The range between means and extremes is much smaller than on Borneo due to the warm influence of the South China Sea. Extreme highs are only about 4-6°F (2-3 °C) hotter than the means. Extreme highs range from 90°F (32°C) in January to 94°F (34°C) in April. Extreme lows range from 68°F (20°C) in January to 71°F (22°C) in April.

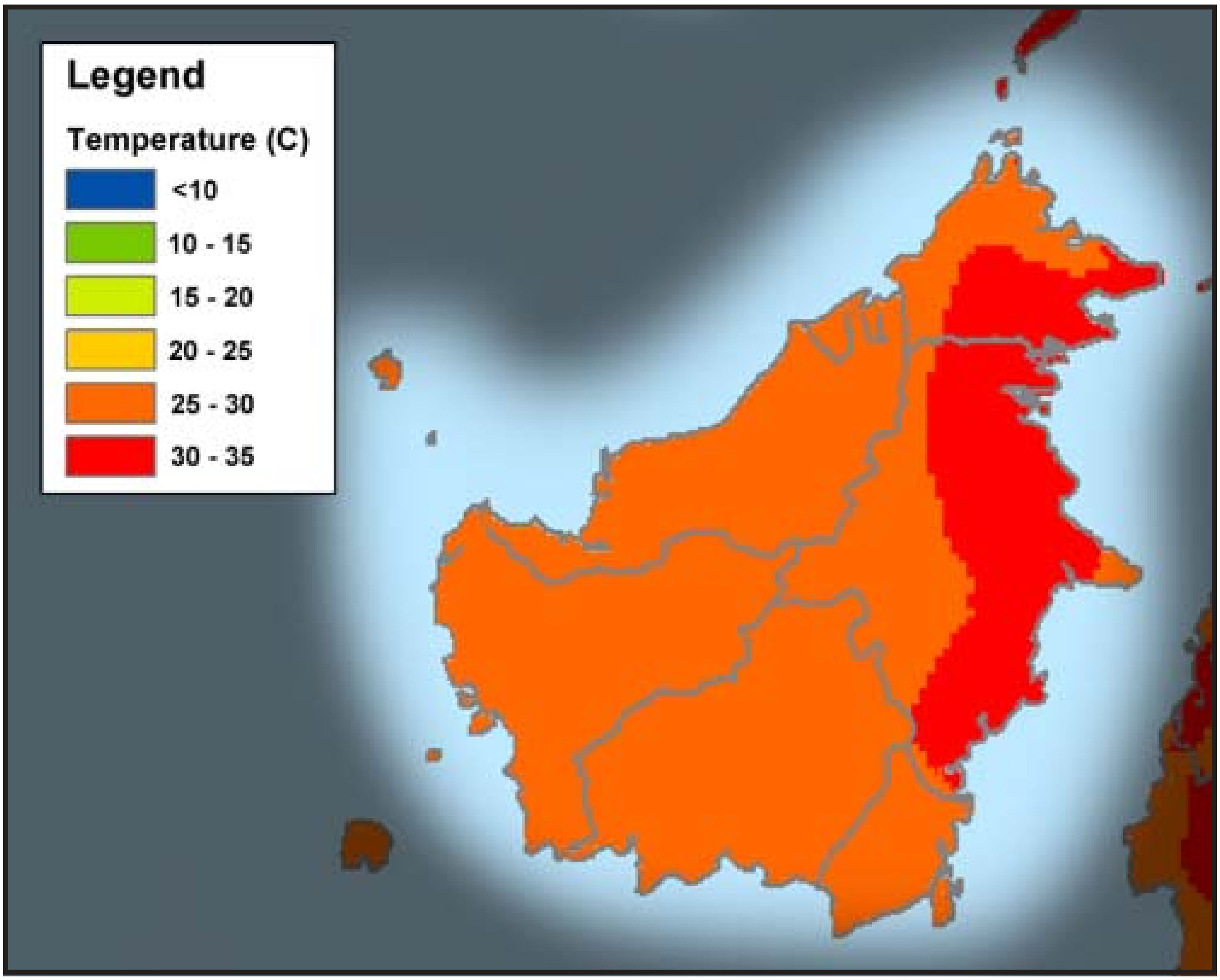

Figure 4-9. January Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the coldest month of the northeast monsoon season. Daily high temperatures are often higher than the mean. Mean maximum temperatures during other months may be higher, especially at the beginning and ending of the season.

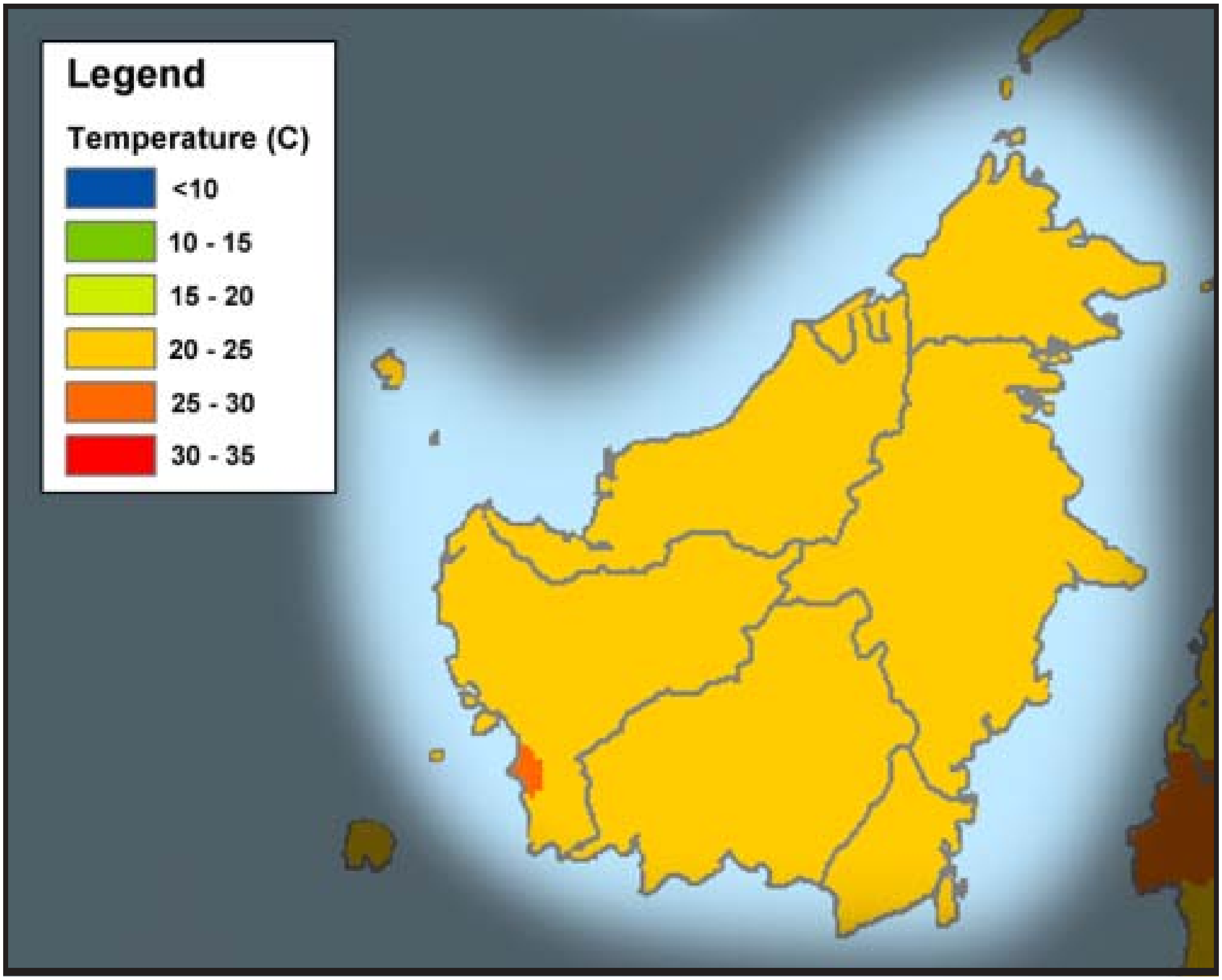

Figure 4-10. January Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the coldest month of the northeast monsoon season. Daily low temperatures are often lower than the mean. Mean minimum temperatures during other months may be higher, especially at the beginning and ending of the season.

Hazards

Tropical Cyclones. On rare occasions, tropical storms that move from east to west across the Celebes Sea or the South China Sea may affect the area northeast of Borneo. Typhoons typically track north of the island, but when they do affect Borneo, they bring heavy rain, high surf, storm surges and extremely strong winds. The rain with typhoons falls in a relatively brief period and causes flash floods along Borneo's rivers.

Flooding. Tropical thunderstorms and tropical cyclones release an incredible amount of rain in a very short time. Most convective activity is associated with convergence zones and tropical cyclones. Flash flooding occurs frequently in the valleys and the lowlands when the rivers and streams are unable to cope with the massive amounts of water.

Turbulence. Turbulence may be encountered at any time and is usually associated with convection or strong winds over rough terrain. Moderate-to-severe turbulence is most likely to occur in and around afternoon thunderstorms. Orographic turbulence may be encountered to some extent over the highlands, especially near the crest of ridges.

Aircraft Icing. Severe icing conditions are particularly a threat in the southwest monsoon, as towering cumulus and cumulonimbus clouds extend above the freezing level. The freezing level is 14,000-16,000 feet, in the southwest monsoon but can drop to as low as 8,000 feet in a cold surge during the northeastmonsoon.

Thunderstorms. Thunderstorms primarily occur in April-May and October-November when the NETWC moves across the island. Thunderstorms generally have severe turbulence and icing, strong downburst winds, and brief periods of extremely heavy rain. On occasion, hail results from thunderstorms, usually only at higher elevations.

Foehns. These hot, dry winds are common to the lee side of the primary ranges and central highlands. Te direction of the prevailing monsoonal flow determines which side of the mounains is the lee side. Foehns desiccate forests and crops. Forest fires are common in lengthy foehn episodes. Extremely strong foehn gusts occur during surges in the monsoon and cause localized destruction to property and livestock.

General Weather. During May, a thermal low over Pakistan replaces the cold Asiatic high over the Asian continent. The Australian high intensifies and the North Pacific subtropical ridge strengthens and moves northward across the western Pacific. The NETWC, which moves northward across Borneo from mid-March to mid-May, allows air masses from the Indian Ocean, Australian, and South Pacific highs to penetrate north of the equator as the southwest monsoon forms.

May begins with the NETWC over northern Borneo; southern portions of Borneo are already under the southwest monsoon. Movement of the NETWC is irregular due to the northward and southward interplay of monsoon surges, particularly over the highlands. When active, the NETWC is evident on streamline charts as a series of quasi-stationary vortices or closed lows. These lows tend to form on the lee side of hills or over areas of higher temperatures. Although the movement of the lows usually generates heavy convection and rainfall, there is rarely a continuous line of clouds and precipitation along the NETWC axis. Convergence zones or vortices within the NETWC control convection. When strong, these vortices extend up to 500 mb. Widespread convergence usually brings heavy cloudiness, showers, and thunderstorms. On the other hand, weak, nearly parallel flow may result in only light cumulus buildup with scattered showers. During the transition, most interior stations not exposed to the monsoons receive their maximum rainfall.

The NETWC normally moves north of Borneo by late May, which puts the entire island under the southwest monsoon. The monsoon provides moist, unstable, southeasterly flow across southern Borneo that shifts to southwesterly flow over northern Borneo as it crosses the equator. The NETWC reaches peak intensity and northernmost position in July and August. Much of Borneo on the lee side of mountains experiences little rainfall, however, isolated coastal regions directly exposed to monsoonal flow receive maximum rainfall at this time.

During monsoonal breaks, weak low-level westerlies may be replaced by easterlies. Precipitation increases significantly as disturbances move along the two branchesof the NETWC. These disturbnces bring short, but intense rain spells to Borneo.

During late September and October, the Asiatic thermal low is replaced by the Asiatic high, while the North Pacific high retreats equatorward. The Australian high is replaced by the Australian low. The southern descent of a weaker subtropical ridge in the western Pacific allows the NETWC to move south into Borneo by mid-October to mid-December. Showers and thunderstorms accompany it through northern Borneo. Southern Borneo is still under the weakening southwest monsoon.

Sky Cover.

Northern Coastal Region. Most ceilings below 3,000 feet occur at the beginning and end of the season when the NETWC is present. Generally, low ceilings occur less during the southwest monsoon because the northern coast is on the lee side of the central highlands. Generally, the greatest frequency of low ceilings occurs with late afternoon or evening convection. Thunderstorms form over the Schwaner and Muller Mountains and drift over te northern coastal region in late afternoon. By mid evening, they flatten to form a ceiling that usually dissipates by midnight. Clear-to-scattered conditios occur late at night. The cloudiest spot in the area i Kuching. Kuching records ceilings below 3,000 feet nearly 50 percent of the time during the afternoons of May and October, but lss than 30 percent of the time during the afternoons in July and August. While other locations in the northern coastal region record low ceilings much less frequently (10-20 percent of the time), they also record low ceilings with the least frequency at the height of the southwest monsoon (July) and with the greatest frequency during the transition months. See Figure 4-11.

Central Highlands. Monsoonal flow against mounain ridges produces cumulus cloud banks on windward slopes and over most mountain peaks. The late morning sea breeze thickens cloud banks and often produces towering cumulus or cumulonimbus on the slopes. Ridges above 3,000 feet are often cloaked for days at a time. Low ceilings are most frequently observed in the predawn hours and during the afternoon. Convective clouds may remain on the windward slopes and ridgs all night. Cleaing is common on the lee side of the mountains; however, it is common for the steering flow to carry rainshower activity from the ridges to the northern coast. Thunderstorms occur most when the NETWC passes over the region. This is the period Sintang records the highest percentage of ceilings below 3,000 feet, 60-70 percent of the time.

Ceilings below 1,000 feet are nearly as common as ceilings below 3,000 feet. Most of the season, clouds shroud the interior mountains. Nocturnal stratus forms a ceiling below 1,000 feet 30-45 percent of the time at Sintang. Ceilings below 500 feet are less common. The highest frequency of ceilings below 500 feet occurs 15 percent of the time in September.

Southern Lowlands. Most low ceilings in the southern half of Borneo occur in the south-central lowlands. Warm, moist, southeasterly flow is trapped by the mountains to the west, north, and east. Pangkalanbuun records low ceilings more than 80 percent of the afternoons while Panarung records them almost 75 percent of the afternoons, with peak occurrence in May and October. Low ceilings are so pervasive across the southcentral lowlands, the NETWC only increases the rate by 5-10 percent of the time. Ceilings below 3,000 feet are nearly as prevalent across the southwestern lowlands. Pontianak records low ceilings 60-70 percent of the afternoons, with the highest rate in May and October. In early mornings, low ceilings occur at least 25 percent of the time in July and August, and 40 percent of the time in May and October. Low ceilings form along the western slopes of the Bungo Range and the Schwaner Mountains as the southeasterlies shift to southwesterlies in the cross-equatorial flow. Low ceilings occur 15-25 percent of

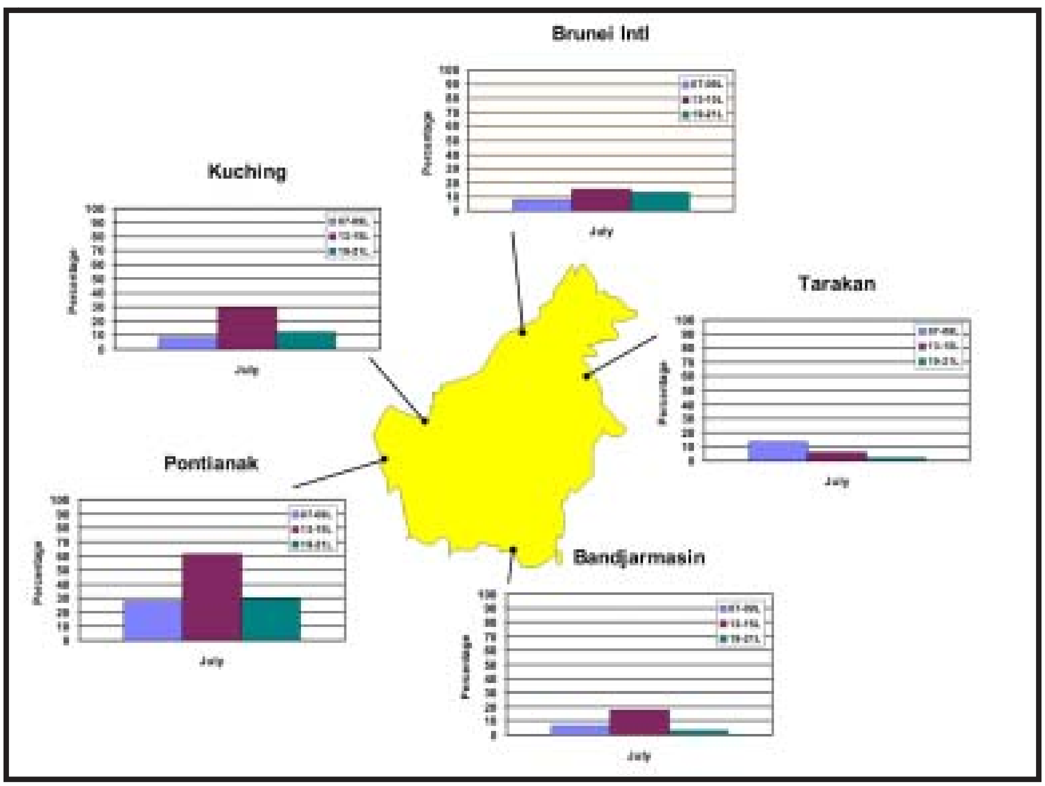

Figure 4-11. Southwest Monsoon Season Percent Frequency of Ceilings below 3,000 Feet for May to October. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet, based on location and diurnal influences.

the time across the southeastern lowlands in July and August.

Anambas and Natuna Islands. The occurrence of ceilings below 3,000 feet at Terempa closely follows the NETWC. During the transition months of May and October, low ceilings occur 25-35 percent of the time, primarily in the early afternoon. As the NETWC moves out of the area, the frequency of low ceilings decreases. From June-August, low ceilings occur at Terempa less than 20 percent of the time. Convective activity is also at its greatest during the transition months of May and October. Ranai records low ceilings 33 percent of the time during the late-night hours, a result of MCCs that form off the northwest coast of Borneo. At the height of the season, cumulus clouds form over the islands but rarely develop into thunderstorms.

Visibility.

Northern Coastal Region. Most stations record visibility below 3 miles (4,800 meters) less than 5 percent of the time. Foehn winds from the Muller and Schwaner Mountains inhibit fog formation. Kuching records low visibility most frequently, 15 percent of the mornings, mainly because of heavy rainfall from MCCs off the coast. Afternoon haze occasionally causes visibility to fall below 6 miles (9,000 meters) across the region. Widespread rain sufficient to greatly reduce visibility is rare. See Figure 4-12.

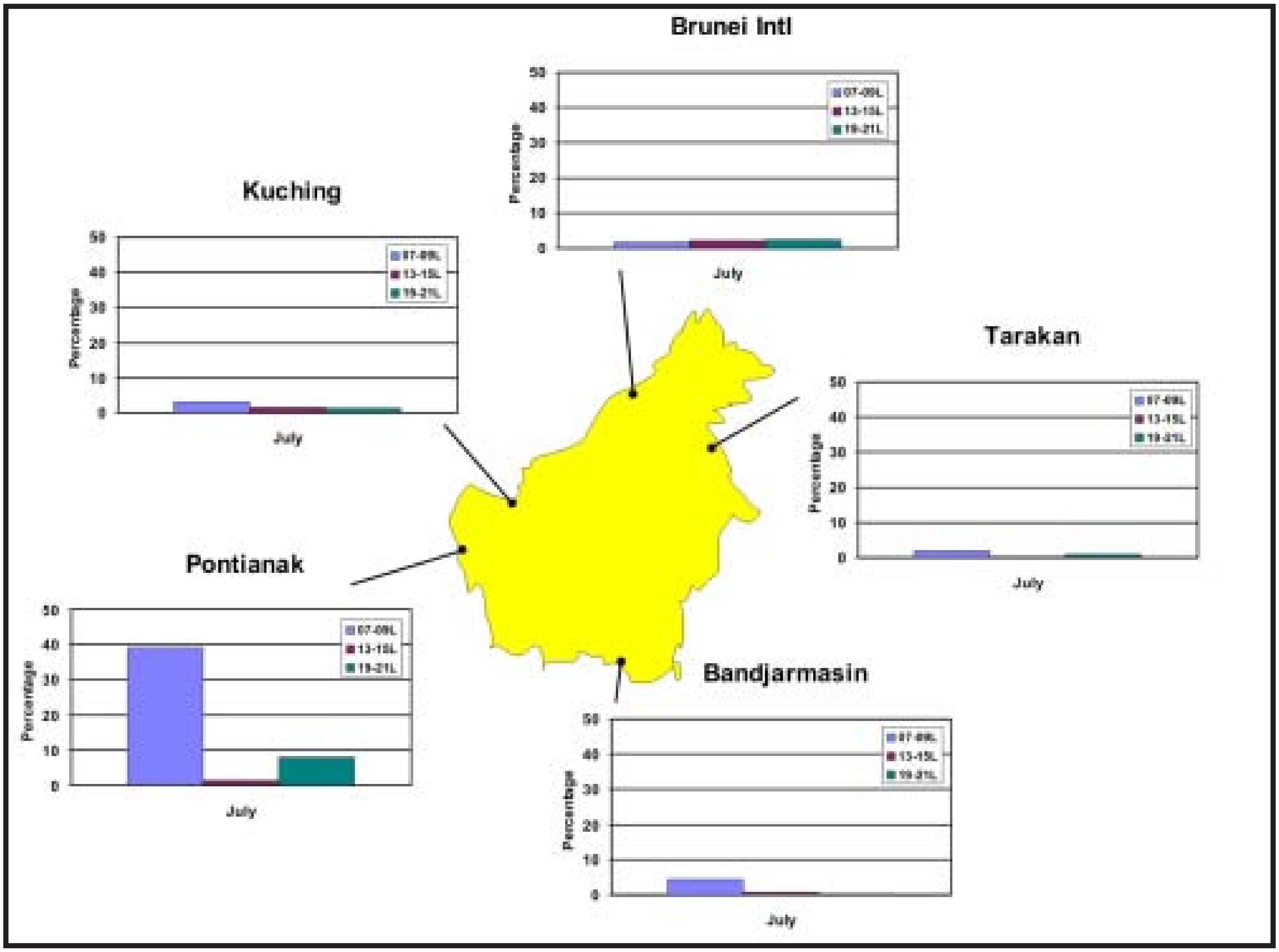

Figure 4-12. Southwest Monsoon Season Percent Frequency of Visibility below 3 Miles (4,800 Meters) for May to October. The graphs show a monthly breakdown of the percent of visibility below 4,800 meters, based on location and diurnal influences.

Central Highlands. Ground fog occurs in enclosed upland basins and inland swamps and rivers. The interior mountains take the brunt of the southwest monsoon and the heavy rain creates a prime area for late-night and early-morning radiation fog. Sintang records low visibility more than 60 percent of the time in May. After the NETWC moves north of Borneo, the fog rates in June and July drop to 40 percent of the time. By early afternoon, fog burns off, and low visibility is recorded less than 5 percent of the time. Fog occurs most in August and September; approximately 70-80 percent of the time at Sintang. As the NETWC approaches in September and October, morning fog tends to persist into the afternoon up to 15 percent of the time. Visibility drops below 1 mile (1,600 meters) less than 10 percent of the time, except during August, 17 percent of the time, and September, 19 percent of the time.

Southern Lowlands. Ground fog forms around swamps and rivers and occasionally over lowlands after showers. Widespread rain sufficient to greatly reduce visibility is rare. Fog is the primary visibility restriction, and it burns off by late morning. Visibility across the southeastern lowlands is below 3 miles less than 10 percent of the time except during October when it increases to 13 percent. Across the southcentral lowlands, low visibility occurs less than 5 percent of the time in May-August. The percentage increases to 20-25 percent of the time in September and October. In Pangkalanbuun the incidence of visibility less than 4,800 meters doubles from 20-25 percent of the time in May and June to more than 50 percent of the time in September and October. Visibility under 1 mile occurs less than 10 percent of the time per month, except for September and October, when it happens 30 percent of the time. Across the southwestern lowlands, occurrences of visibility less than 4,800 meters increase from 23 percent of the time in May to 54 percent of the time in August. Instances of visibility less than 1 mile (1,00 meters) jump from 11 percent of the time in May and October to 34 percent of the time in August.

Anambas and Natuna Islands. Visibility under 4,800 meters occurs less than 10 percent of the time.

Surface Winds. Winds are more variable this season due to the weaker monsoonal flow. Prevailing flow is often masked by local influences. High winds are commonly reported with heavy convection. Winds with the NETWC are light and variable during the transitions.

Northern Coastal Region. Terrain, local effects and funneling of winds are much greater factors than the monsoonal flow in wind speed and direction. Along the shore, the northerly afternoon sea breeze (6-15 knots) tends to damp the southwest monsoon. A convergence line usually forms in the afternoon where the sea breeze and the monsoonal flow interact. As the Australian high periodically disappears, the southwest monsoon is disrupted. This allows the sea breeze to strengthen and dominate the northern coast. Once the southwest monsoon redevelops and strengthens, the line of convergence is pushed offshore. Under these conditions, a weak, nocturnal land breeze (3-8 knots) is present. Channeled winds from a nearby pass in the Crocker Mountains causes an easterly wind at Kinabalu. Breezes from nearby river valleys occur at Brunei and Bintulu from mid morning until late afternoon. In the evening, the wind dies out.

Central Highlands. Southerly foehns are common. Foehns commonly occur in the lee of the mountains near the Kapuas River valley. Monsoon surges increase the effect foehns have on the region. The complex interior geography of Borneo causes winds to be channeled and funneled through numerous minor river valleys. Mean afternoon wind speeds are 10-15 knots. Speeds normally drop off after dark in the valleys as the radiation inversion sets up. Below the inversion, winds are calm 40 percent of the time and less than 6 knots the rest of the time. Above the inversion, speeds are accelerated at mountain-top level as a low-level jet forms. Wind speeds of 20-30 knots are common in the jet. After the inversion breaks, the gradient winds once again mix to the surface. A wind burst is common when the inversion breaks if high winds are present above an exceptionally strong inversion. Monsoon surges also cause increased wind speeds of the low-level jet and surface wind. Speeds of 35-40 knots occur, especially in valleys parallel to mean wind flow.

Southern Lowlands. Across the southeast, the sea breeze is enhanced by monsoonal flow. This not only increases the mean wind speed, it also forces the sea-breeze front farther inland, to the mountains of southeastern Borneo. During monsoon breaks, the sea-breeze front forms much nearer the coast. Nearby terrain influences the nocturnal land breeze at Balikpapan. A consistent 10-15 knot westerly land breeze is present at Balikpapan. This steady breeze is formed as wind from the interior is forced through a mountain pass 40 miles (65 km) west-northwest of the city. This breeze usually forms by mid-evening and lasts until dawn. Winds in the crossover hours are typically light and variable. Across the southcentral lowlands, the sea breeze is very weak and only penetrates a short distance inland. For most of the region, calms are recorded 60-80 percent of the time. The coastal stations of Pangkalanbuun and Panarung record a weak southerly breeze that rarely exceeds 15 knots 20-30 percent of the afternoons. The rest of the time, winds are light and variable. The southwestern coastal city of Pontianak records calms 60-80 percent of the time, but a weak, nocturnal easterly land breeze blows. This feature rarely exceeds 10 knots, and occurs 20-30 percent of the time. A weak southwesterly sea breeze, rarely over 10 knots, occurs 20-30 percent of the time. See Figure 4-13.

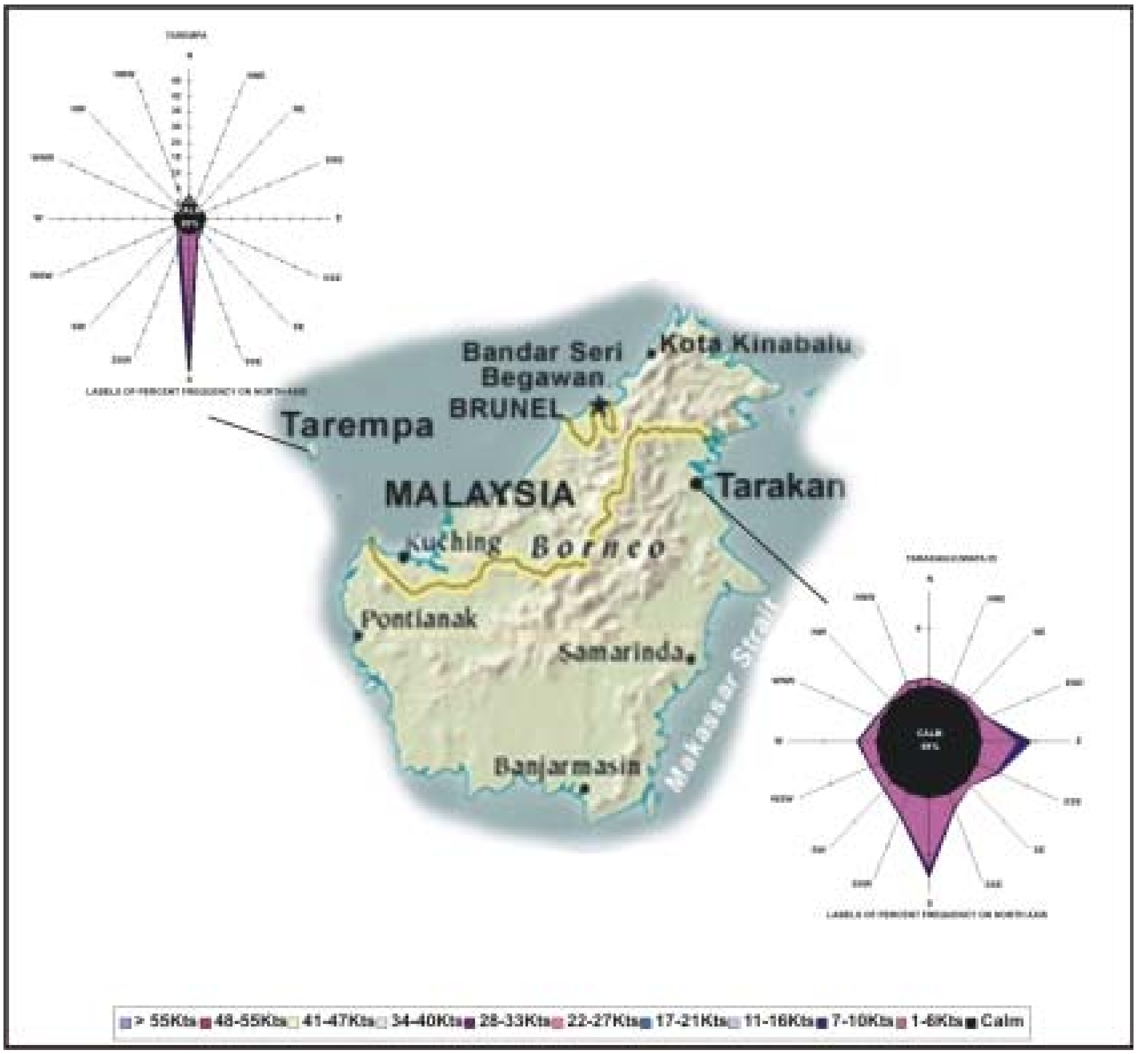

Figure 4-13. July Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds, based on frequency and location.

Anambas and Natuna Islands. Monsoonal flow dominates. The land/sea breeze is negligible, as are the effects of terrain. Calms occur 35-45 percent of the time at Terempa. Southerly winds of 10-15 knots occur the other 55-65 percent of the time. Since Natuna Island is much larger, terrain has a greater effect on the winds. Ranai has a distinct westerly or southwesterly nocturnal land breeze that occasionally reaches 18 knots. In the afternoon, the winds are more southerly and weak. Calms occur 60-75 percent of the time.

Upper-Level Winds. As the southwest monsoon starts in May, southwesterly winds blow from the surface to 8,000 feet. Easterlies prevail above 8,000 feet. Mean wind speeds in the lower levels are 10-15 knots, and get as high as 30 knots 10 percent of the time. Speeds are consistent to 300 mb, where they rarely exceed 30 knots. In July and August, southwesterly flow occurs as high as 15,000 feet. Wind speeds average 15-25 knots at 850 mb and gradually increase through the layer to 35-45 knots at 15,000 feet. In the upper levels, the easterlies reach speeds up to 60 knots 10 percent of the time. Southwesterlies in the lower levels rapidly retreat by September and October. Southwesterlies only extend as high as 8,000 feet. Speeds at all levels generally decrease as the NETWC approaches, but southwesterlies at 850 mb still exceed 30 knots 3 percent of the time. See Figure 4-14 for wind roses at selected locations.

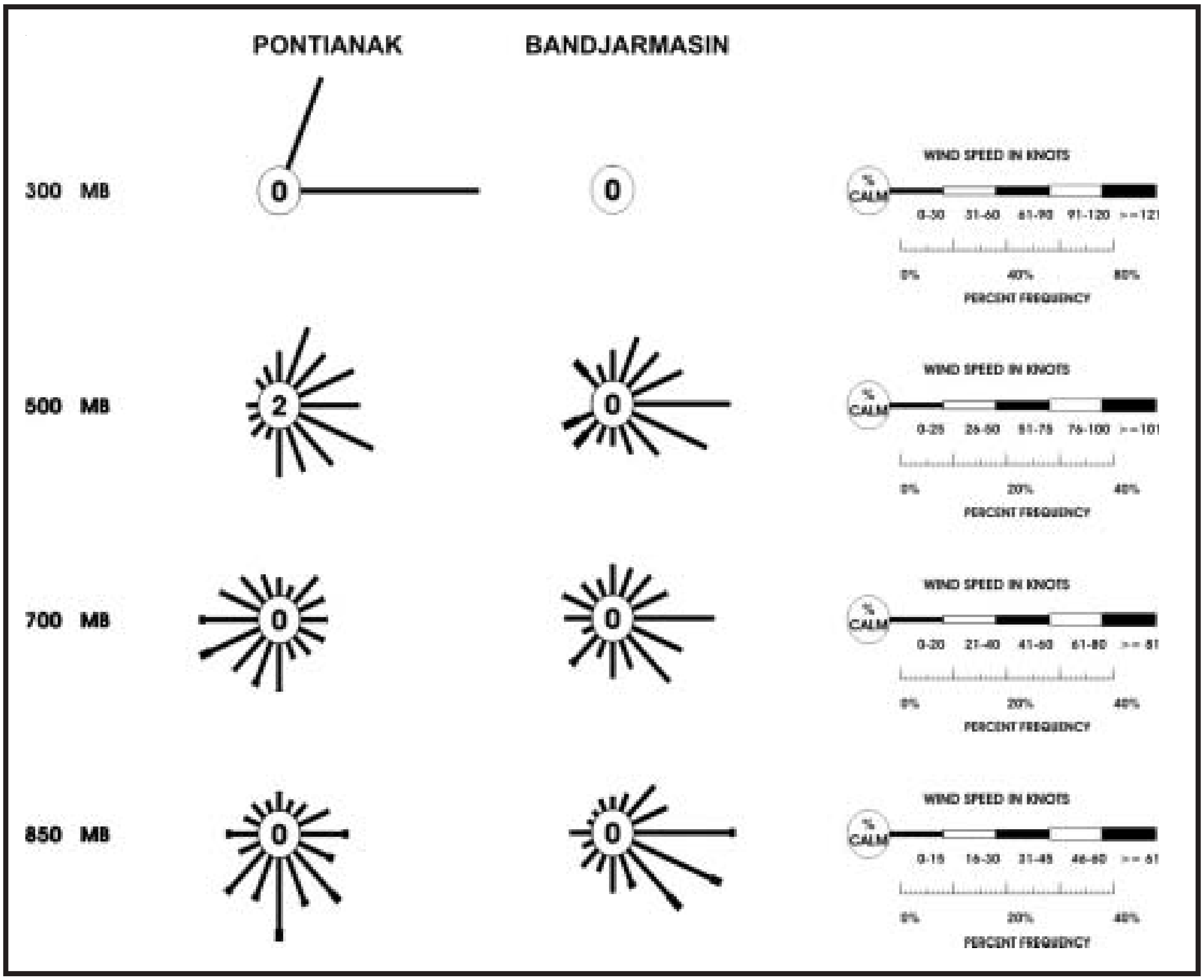

Figure 4-14. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 mb and 300 mb for selected locations.

Precipitation.

Northern Coastal Region. In July and August, the area has its annual rainfall minimum. Most stations are on the lee of the mountain and receive 4-8 inches (100-200 mm) of rain in July and August. Stations in the Crocker and Muller Mountains receive 12-18 inches (300-450 mm) of rain per month. Southwest monsoon precipitation totals for most stations are highest in May. A secondary maximum is reached in October. The area around Kuching is one of the driest on Borneo during the southwest monsoon. The 8 inches (200 mm) of rain Kuching has in July is contrasted by the 26 inches (650 mm) it has in January.

Central Highlands. Precipitation is closely related to elevation. Totals are greatest in the northern, higher mountains. Totals average 12-18 inches (300-450 mm) in the northern Muller Mountains and barely 6-9 inches (150-225 mm) in the southernmost parts of the region. Ridges perpendicular to prevailing southerly flow receive more rainfall than parallel ridges. Thunderstorms are most common when the NETWC is nearby, but continue to occur because of the orographic lift provided by the mountains.

Southern Lowlands. This is driest part of Borneo during the southwest monsoon. Most of the area has 3-6 inches (75-150 mm) of rain in July and August. Only a small part of the southeastern lowlands near Balikpapan has as much as 7 inches (175 mm) of rain in July. A small area on the lee of the southeastern mountains near Bandjarmasin has only 3 inches (75 mm) of rain in July. Rainfalls are slightly higher along the northern fringes of the southcentral lowlands. Upslope in the foothills along the southern periphery of the central highlands causes precipitation totals of nearly 9 inches (225 mm) in July (Figures 4-15 and 4-16).

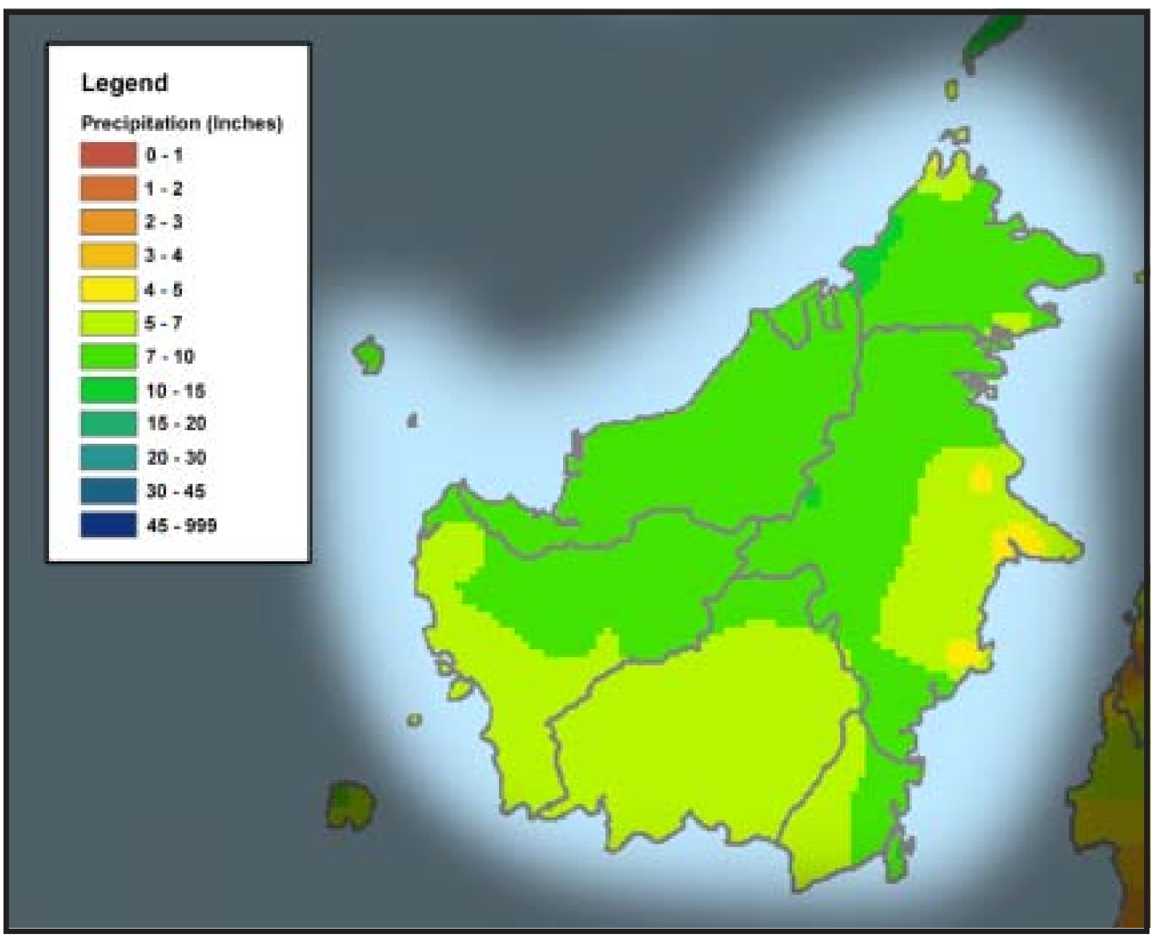

Figure 4-15. July Mean Precipitation. The figure shows precipitation amounts in the region.

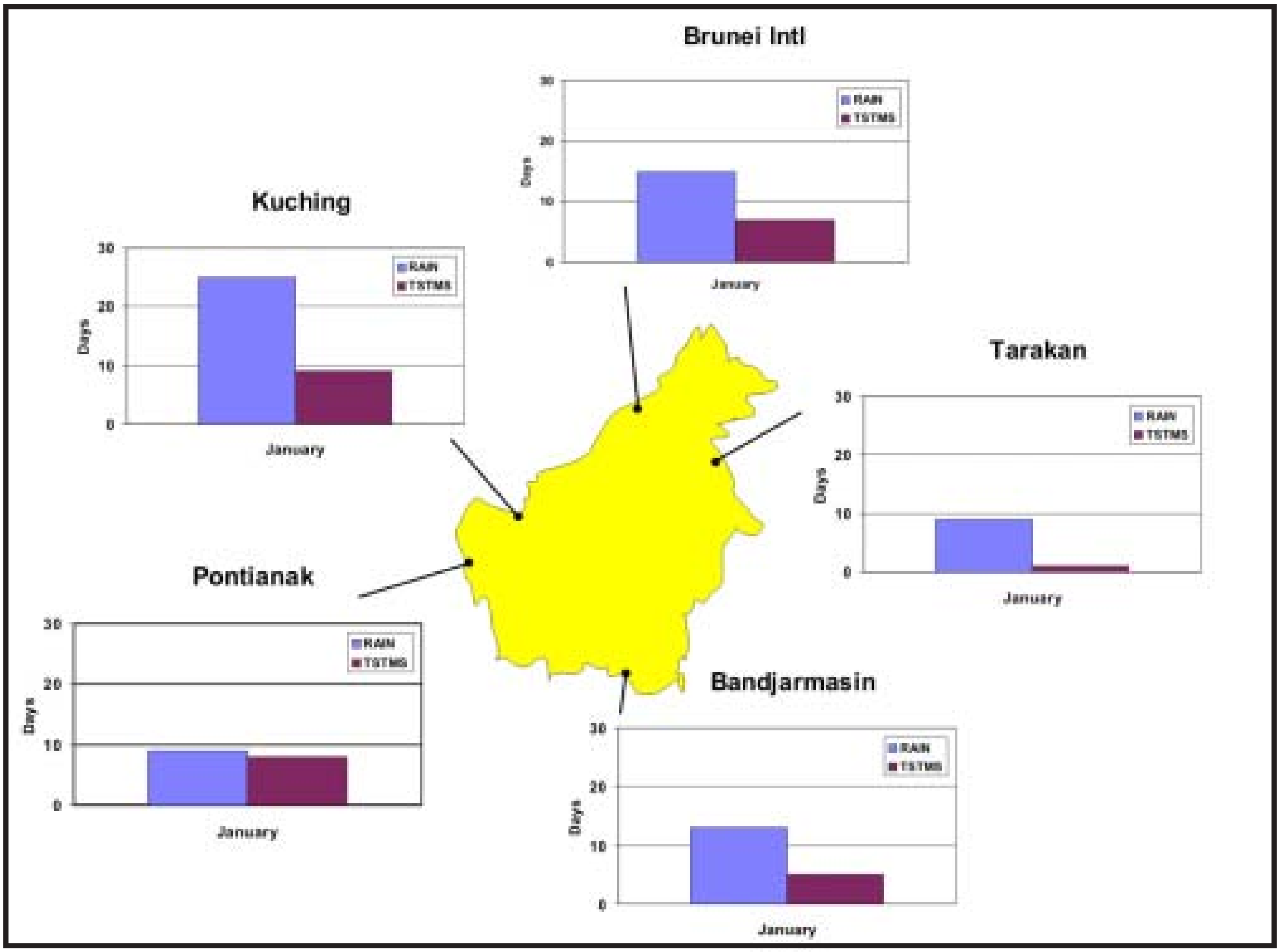

Figure 4-16. Southwest Monsoon Season Mean Rain and Thunderstorm Days. The graphs show the average seasonal occurrences of rain and thunderstorm days for representative locations in the region.

Anambas and Natuna Islands. The driest month of the year at Terempa is July, which has less than 5 inches (125 mm) of rain that month. The rest of the season, Terempa records an average of 6 inches (150 mm) of rain per month until October. As the NETWC moves southward through the area, precipitation doubles to about 12 inches (300 mm) of rain in October. During the southwest monsoon, Terempa is in the rain shadow on the lee of the line of hills along the western coast of Siantan Island. The situation reverses in October, as the northeast monsoon approaches and places Terempa on the windward side.

Temperatures. Temperatures are very warm and usually accompanied by high humidity. They are fairly uniform, and cool with elevation moist-adiabatically. Diurnal variations in mean temperatures exceed annual changes in mean temperatures, particularly in the central highlands. Temperature is also a function of cloud cover. Areas covered by thick clouds do not heat as quickly as those without the cover. Once the clouds pass or dissipate, the ground heats quickly.

Northern Coastal Region. Foehns are prevalnt on the lee side of the mountains during July and August. These winds cause a 1-2 Fahrenheit (1 Celsius) degree increase in the diurnal range. The generally drier, less cloudy air causes the mean daily highs to be slightly warmer and the mean daily lows to be slightly cooler. Temperatures in the higher elevations are normally 3 Fahrenheit (5.5 Celsius) degrees cooler for every 1,000 foot rise. Since the air at the top of the mountains is nearly always saturated, the range between means and extremes is smaller than for stations at sea level. The range of mean highs and mean lows at coastal stations is insignificant. Most stations record a mean high of 86° to 91°F (30° to 33°C) and a mean low of 72° to 75°F (22° to 24°C). Extreme highs for most locations are 96° to 101°F (36° to 39°C) with extreme lows near 60°F (16°C). See Figure 4-17.

Central Highlands. Mean highs in the highlands are 72° to 78°F (22° to 26°C) at 5,000 feet and about 63° to 70°F (17° to 22°C) at 8,000 feet. Mean daily minimums are 56° to 62°F (13° to 17°C) at 5,000 feet and 48° to 52°F (9° to 11°C) at 8,000 feet. The western highlands, near the Kapuas River, are most prone to foehns and record the hottest extreme highs; they occasionally exceed 100°F (38°C). Extreme lows are not as cold during the southwest monsoon as they are under the northeast monsoon. This is because the source for cold surges in this season (Australian anticyclone) is not as strong, or cold, as the Asiatic high. Under exceptionally strong cold surges from the Australian high, the temperatures at the highest heights of the central highlands occasionally drop to near 40°F (5°C). At elevations near 5,000 feet, mean temperatures are 15 Fahrenheit (8 Celsius) degrees cooler than at sea level. At the highest elevations of the central highlands, near 8,000 feet, means and extremes are 24 Fahrenheit (13 Celsius) degrees cooler. Cloud cover moderates temperatures; most of the central ridges are covered by clouds most of the season.

Southern Lowlands. The greater maritime influence, along with increased cloud cover, moderates temperatures and decreases the diurnal range during the southwest monsoon. Mean highs are 82° to 86°F

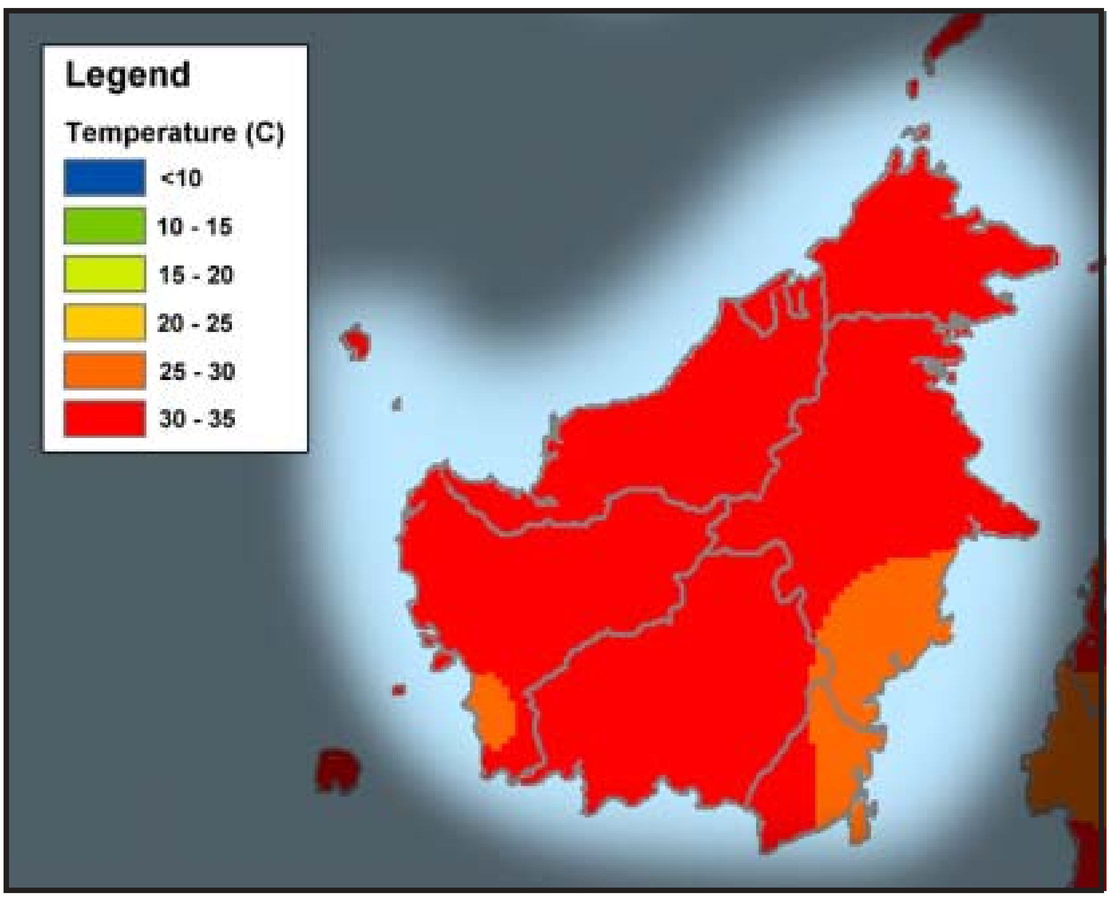

Figure 4-17. July Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the warmest month of the southwest monsoon season. Daily high temperatures are often higher than the mean.

(28° to 30°C), while mean lows are 73° to 77°F (23° to 25°C). Several locations have recorded extreme high near 100°F (38°C). Extremely hot temperatures primarily occur when cloudiness is at a minimum and when offshore flow prevails and minimizes the maritime influence. The lowest extreme low across the southern lowlands was 60°F (16°C) at Balikpapan.

Anambas and Natuna Islands. The air temperature of both groups closely follows the sea-surface temperature and relates to the position of the sun. The mean highs range from 87°F (31°C) in October to 90°F (32°C) in May. Mean lows average 75°F (24°C). Because of the warm, South China Sea, the range between means and extremes is much smaller than on Borneo. Extreme highs are only about 4-6 Fahrenheit (2-3 Celsius) degrees hotter than the mean highs. Extreme highs range from 92°F (32°C) in July to 94°F (34°C) in May and September. Extreme lows range from 69°F (21°C) in July to 72°F (22°C) in May. See Figure 4-18.

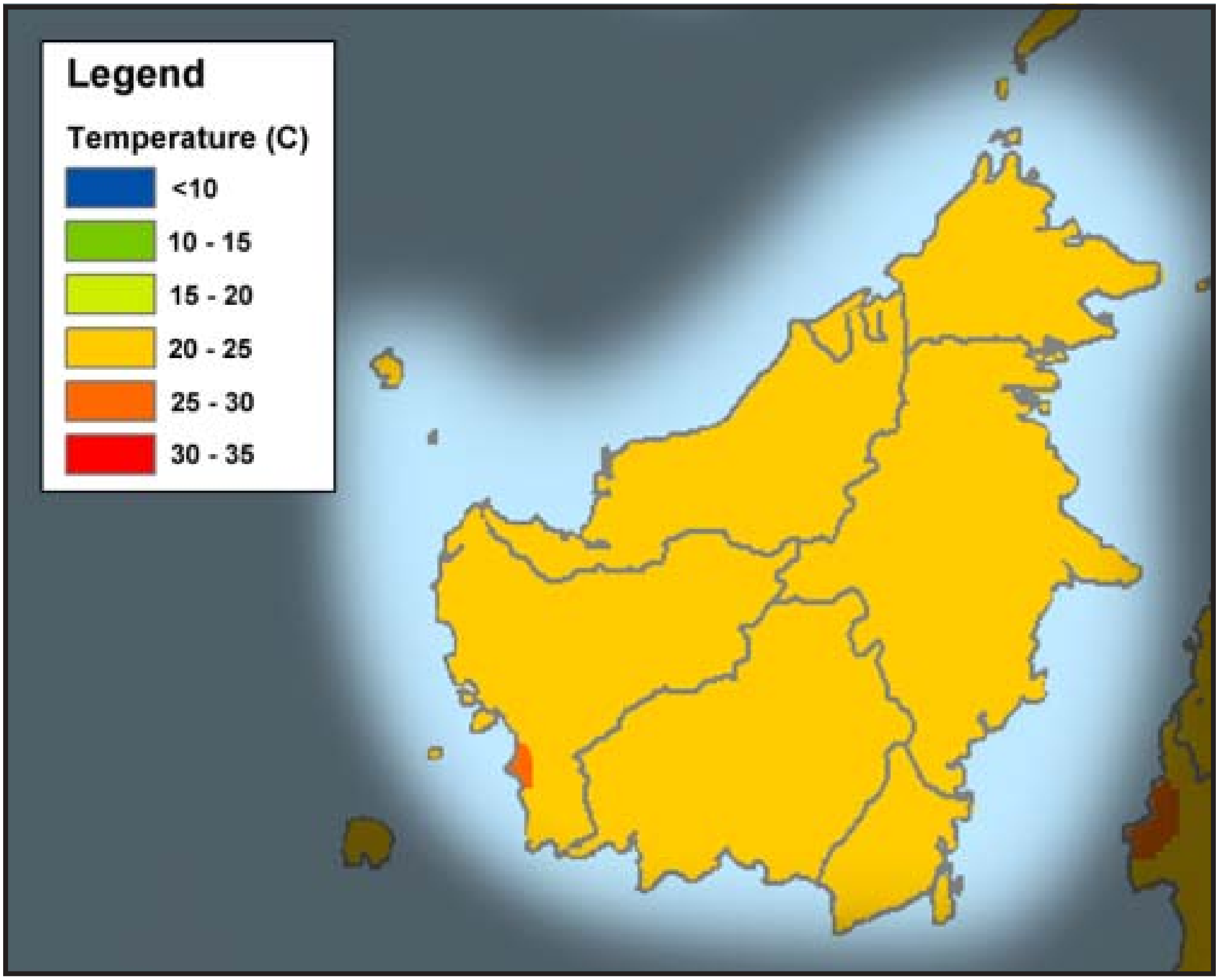

Figure 4-18. July Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the warmest month of the southwest monsoon season. Daily low temperatures are often lower than the mean.

Hazards

Tropical Cyclones. On rare occasions, tropical storms that move from east to west across the Celebes Sea or the South China Sea may affect the northeast of Borneo. Typhoons typically track north of the island, but when they do affect Borneo, they bring heavy rain, high surf, storm surges and extremely strong winds. The rain with typhoons falls in a relatively brief period and causes flash floods along Borneo's rivers.

Flooding. Tropical thunderstorms and tropical cyclones release an incredible amount of rain in a very short time. Most convective activity is associated with convergence zones and tropical cyclones. Flash flooding occurs frequently in the valleys and the lowlands when the rivers and streams are unable to cope with the massive amounts of water.

Turbulence. Turbulence may be encountered at any time and is usually associated with convection or strong winds over rough terrain. Moderate-to-severe turbulence is most likely to occur in and around afternoon thunderstorms. Orographic turbulence may be encountered to some extent over the highlands, especially near the crest of ridges.

Aircraft Icing. Severe icing conditions are particularly a threat in the southwest monsoon, as towering cumulus and cumulonimbus clouds extend above the freezing level. The freezing level is 14,000-16,000 feet, in the southwest monsoon but can drop to as low as 8,000 feet in a cold surge during the northeast monsoon.

Thunderstorms. Thunderstorms primarily occur in April-May and October-November when the NETWC moves across the island. Thunderstorms generally have severe turbulence and icing, strong downburst winds, and brief periods of extremely heavy rain. On occasion, hail results from thunderstorms, usually only at higher elevations.

Foehns. These hot, dry winds are common to the lee side of the primary ranges and central highlands. Th direction of the prevailing monsoonal flow determines which side of the mountins is the lee side. Foehns desiccate forests and crops. Forest fires are common in lengthy foehn episodes. Extremely strong foehn gusts occur during surges in the monsoonand cause localized destruction to property and livestock.

Chapter 5

THE ISLANDS OF CELEBES, THE MOLUCCAS, AND NEW GUINEA

This chapter describes the geography, major climatic controls, special climatic features, and general weather by season for the Celebes, Moluccas and New Guinea climatic commonality zone in the Western Pacific Basin. See Figure 5-1.

Figure 5-1. Islands Of Celebes, The Moluccas, and New Guinea. The figure shows the location of the Islands Of Celebes, The Moluccas and New Guinea in relation to other countries in the Western Pacific region.

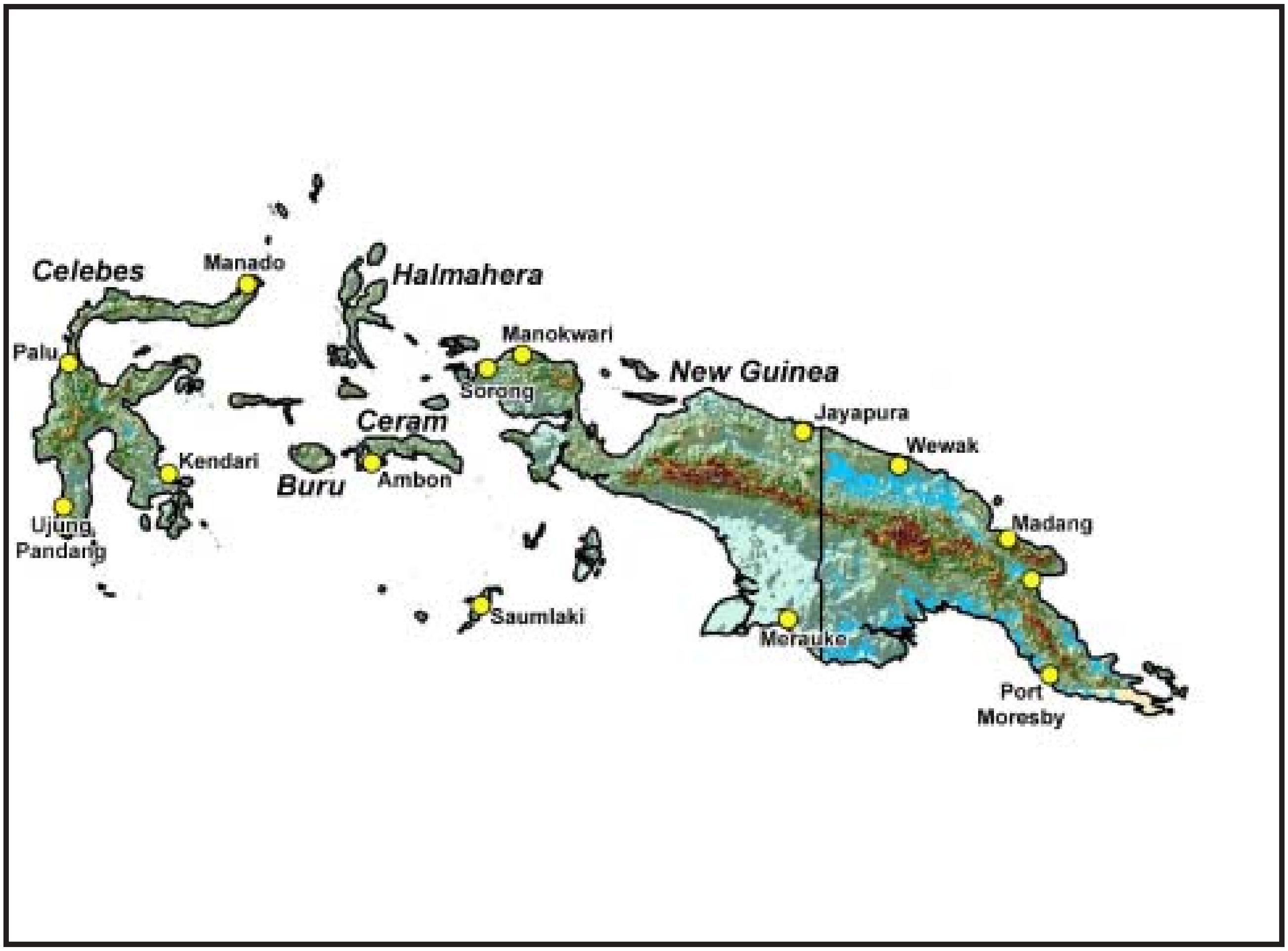

Figure 5-2. Topography Map of the Islands of Celebes, Moluccas and New Guinea.

TOPOGRAPHY. The islands in this zone are located in the western Pacific Ocean. The total area extends from roughly 3° N to 11° S, and from 119° E to 151° E. The islands, except for the eastern part of New Guinea, are part of the Republic of Indonesia. The eastern part of New Guinea is the independent state of Papua New Guinea.

Celebes (also called Sulawesi) is in the shape of an inverted lowercase "y", with the long tail of the "y" extending north, then east from the main body of the island. The island is mountainous, with peaks as high as 11,500 feet (3,500 meters). It has several active volcanoes, primarily in the northern peninsula.

The Boliohutu Mountains reach from the eastern tip of the northern peninsula into most of the northwestern part of the central island. Peaks are 4,500-6,500 feet (1,400-2,000 meters) high. From the center of the island, the Batui Mountains stretch northeast to the tip of the eastern peninsula, and south into the southeast peninsula. At 4° S, in the central part of the peninsula, the terrain descends to less than 1,000 feet (300 meters) and continues down to the coast. In these mountains, most peaks are 5,000-9,000 feet (1,500-2,700 meters). At 1° S, 121° E, a ridge stands at 11,500 feet (3,500 meters), the highest point on the island of Celebes. The Ogoamas Mountains extend from the westernmost part of the northern peninsula southward into the west-central main part of the island, where they join the Kalando and Gandadiwata Mountains. Terrain descends toward the south from 8,000-11,000 feet (2,400-3,400 meters) to 3,000-4,500 feet (900-1,400 meters) near the west central coast to less than 1,000 feet (300 meters) in east central island. From that point the terrain rises abruptly to near 9,500 feet (2,900 meters) in the Lompobatang Mountains on the south central main part of the island.

Several islands and island groups surround Celebes. The Talaud Island group is north of the northern peninsula in the Celebes Sea. The main island is Karakelong with several smaller islands in the group. The Sangihe Islands are a small group of volcanic islands southwest of the Talaud Islands. The largest is 30 miles long by 13 miles wide (48 by 21 km). The Penju Islands are in the eastern part of the Gulf of Tomini. The largest island extends 80 miles (128 km) west to east. The islands are ringed with coral reefs. The highest elevation is 1,800 feet (550 meters) in the central part of the large island.

The Banggai Archipelago is in the Gulf of Tolo off the eastern tip of the eastern peninsula. Peleng Island is the largest in the group. The mountains on the west end of the island rise abruptly from the sea to 3,500 feet (1,000 meters). The eastern part of the island has broad level plains. Butung Island extends north-south for 100 miles (160 km) off the southeast coast of Tenggara. It has volcanic peaks that reach 4,000 feet (1,200 meters) in the northern part of the island. The island is rimmed with fertile coastal plains. Just west of Butung Island, across a narrow channel, is Muna Island. It extends north-south for 63 miles (100 km). It is a low, nearly flat island, with a maximum elevation of less than 1,000 feet (300 meters).

Selajar Island is a long, narrow island in the Flores Sea, 11 miles (18 km) south of the southwestern peninsula. The island is nearly 51 miles (82 km) long with a central ridge of low mountains at nearly 2,000 feet (900 meters) elevation.

Major Water Bodies. Celebes faces the Celebes Sea to the north, the Molucca and Banda seas to the east, and the Flores Sea to the south. In the west, it is separated from Borneo by Makassar Strait. The north and east peninsulas are separated by the Gulf of Tomini. The Gulf of Tolo is between the east peninsula and the southeast peninsula. The Gulf of Bone is between the southeast peninsula and the southwest peninsula.

Rivers, Lakes, And Drainage Basins. The rugged mountains of Celebes are drained by many rivers; most are small and swift-flowing. On the northern peninsula, the Onggak River flows north from the Boliohuto Mountains and empties into the Celebes Sea. The Onggak Demogo flows southwest through a wide valley, then turns northwest to join the Onggak. The Pagujaman River flows southeast from the Boliohuto Mountains to the Gulf of Tolo. The Buhu River flows southwest from the south flanks of the Boliohuto Mountains, and joins the Molango River. The Molango flows to the Gulf of Tolo.

On the eastern peninsula, both the Kaukengka and Bangka rivers rise on the northern flanks of the Batui Mountains. They flow northwest to Tomini Bay. In the central main part of the island, both the Palu River and Lariang River rise on the western flank of the Ogoamas Mountains. The Palu flows north and the Lariang flows west to empty into the Makassar Strait. On the southeastern peninsula, the Lalindo River flows southeast from the Butai Mountains to empty into the Gulf of Tolo. The Konaweha flows southeast and east from the mountains through a large plain to empty in the southern end of the Gulf of Tolo.

There are numerous rift valleys between the mountains ranges in Celebes; many have lakes. One of the largest is Lake Towuti, at the north end of the southeastern peninsula. It is 20 miles long and 15 miles wide at its widest point (37 by 28 km). About 20 miles (37 km) northwest of Lake Towuti is Lake Matano. Lake Matano is long and narrow, 15 by 5 miles (28 by 9 km), and fills a deep valley between ridges. Another large lake, Poso, is in a high valley, at an elevation of 1,700 feet (520 meters) at 1° 50’ S 124° E.

The Moluccas (Maluku Islands). The Moluccas are a group of hundreds of islands between Celebes and New Guinea. There are three large islands, several large island groups, and many smaller groups and individual islands. Many islands rise abruptly from the sea, and have only narrow, low coastal areas. Most are mountainous; many are volcanic and have deep rift valleys.

Halmahera is the largest of the islands in the Moluccas. It roughly resembles a lower case “k”. Its four peninsulas enclose three large bays; Kau Bay on the northeast, Buli Bay on the west and Weda Bay to the southeast. The island is mountainous, with several volcanoes in the western part of the island. Maximum elevation is 5,300 feet (1,600 meters). Off the west coast are two small islands, Ternate and Tidore, which are little more than conical volcanoes. Maximum elevation in these islands is 5,600 feet (1,700 meters). Off the northern coast, Morotai rises from the Halmahera Sea to a maximum elevation of 3,600 feet (1,100 meters). The Batjan Island group is off the southwestern coast. The Obi Island group is south of that. All these islands are volcanic, and quickly rise from the sea to a maximum elevation of 6,926 feet (2,100 meters).

The Obi Island group is the second largest island in the Moluccas. It is south of Halmahera in the Ceram Sea. It has a central spine of high, rugged mountains that top 10,000 feet (3,000 meters). There are broad plains on the north side of the island. There are two smaller island groups near by, one off the west end and another off the southeast end of the main island. Buru Island is 40 miles (64 km) west of Ceram. It is 90 miles long and 50 miles wide (145 x 80 km). Steep mountains rise to nearly 8,000 feet (2,400 meters). In the rift valleys between the ridges are grassy plains.

The Sula Island group is between Celebes and the Ceram Sea. Taliabu and Mongoli, the two main islands, extend west to east for nearly 120 miles (193 km). They are separated by a very narrow channel. A smaller island, Sulabes, extends southward across a narrow channel from Mongoli. The islands are volcanic, with peaks to 5,400 feet (1,650 meters). The Tanimbar Islands are in the Banda Sea, at the eastern end of the Lesser Sundas. The largest are Jamdena, Larat and Selaru. These are coral islands with maximum elevations under 1,000 feet (300 meters). The islands have extensive swamps and few good harbors. The Aru Islands are a group of one large and 90 small, coral islands off the southwest coast of New Guinea in the Arafura Sea. The main island, Tanahbesar, is divided into six separate sections by narrow channels. The island is low and fairly flat, with the highest elevation only 700 feet (210 meters).

To the west of the Aru group is a smaller group, the Kai Islands. The largest, Besar, is long and narrow with a central mountainous spine. Volcanic peaks reach 3,000 feet (900 meters). The smaller islands west of Besar are mostly coral with a few peaks up to 1,800 feet (550 meters). Most smaller islands are low and relatively flat, with extensive marshes and swamps.

Major Water Bodies. The Moluccas are bounded on the north by the Pacific Ocean, on the west by the Molucca Sea, on the south by the Banda and Arafura seas and on the east by the Pacific Ocean and Halmahera Sea. The Ceram Sea is between the islands of Buru and Ceram to the south and the island of Halmahera to the north.

Rivers, Lakes, and Drainage. The mountains of the Moluccas are drained by hundreds of small, swift-flowing rivers and streams. On the northeast tip of Halmahera, Tiabo River forms a swampy area near its mouth, and mangrove thickets grow along the coastline. The river is one of the few navigable by craft larger than small boats or canoes.

New Guinea. This island extends northwest to southeast, from the equator to 11° S, and from 130° to 151° E. Irian Jaya occupies western New Guinea from 141° E to the west end of the island. Papua New Guinea extends from 141° E to the eastern tip of the island. Tectonic action created both the towering mountain peaks of its central east-west spine, and hot, humid alluvial plains along the coasts. One of the largest alluvial plains in the world extends from the central mountain ranges southward to the coast of New Guinea. Several active volcanoes occupy the northeast coast and the adjacent islands.

Waigeo Island is off the northwest tip of New Guinea. The island is 28 miles wide and nearly 80 miles long (45 by 129 km). Narrow coastal plains rise to elevations as high as 3,000 feet (1,000 meters). The mountains are divided by deep valleys. The Schouten Islands are near the entrance to Sarera Bay on the northwest coast of New Guinea. The largest of the islands is Biak Island. It is 23 miles wide and 45 miles long (37 by 72 km). Supiori Island is at the northwest tip of Biak and is separated from the larger island by a very narrow strait. Both islands are hilly, with peaks up to 3,500 feet (1,100 meters). South coastal areas are low, flat plains and both islands are ringed with coral reefs. Numfoor Island, a small island in the Schouten group, is at the west side of the entrance to Sarera Bay. It is nearly circular, nearly flat, and encircled by coral reefs. Japen Island is in Sarera Bay, south of the Schoutens. It is long and narrow and has a central ridge of mountains nearly its entire length, with the highest peak at 4,907 feet (1,496 meters).

Two volcanic islands are off the northeast coast of New Guinea, and are part of the Bismarck Archipelago. Long Island is separated from New Guinea by the Vitiaz Strait. This circular island is a collapsed caldera whose rim exceeds 4,200 feet (1,280 meters). Lake Wisdom fills the caldera. The volcano rises abruptly from narrow coastal plains. The volcanic island of Karkar is 75 miles (120 km) northwest of Long Island. Its central peak stands at 6,104 feet (1,860 meters). An active volcano is near the northwest coast of the island. The Owen Stanley Range, on the southeast coast of Papua New Guinea, does not end at the coast, but extends eastward, submerged in the southern Solomon Sea. The range protrudes from the sea to form the D'Entrecasteaux Islands at the southeastern end of the main island.

New Guinea is divided by a central spine of mountains. The mountains appear to be one, nearly continuous range, but are actually several ranges interspersed with deep valleys, and grassy plains and plateaus. Between the central ranges and the north coast, are smaller but significant ranges. Another significant mountain range lies along the far southeastern coast of the island.

The Sudirman Range extends from the west end of the island southeast through Irian Jaya to near the Papua New Guinea border. From there, the Bismarck Range bisects Papua New Guinea southeastward to near the southeastern end of the island. North of these ranges, lesser ranges line much of the northern coast of the island. The Finisterre Range, the largest and highest of the north ranges, extends from 145°30' E toward the southeast along the Huon peninsula. The Owen Stanley Range joins the eastern Bismarck Range, and extends southeast to the end of the island. Many peaks in the Sudirman Range in Irian Jaya exceed 15,000 feet (4,600 meters). In the Bismarck Range, peaks and ridges stand at least 12,000 feet (3,700 meters). In the Finisterre Range, on the northeast coast, many peaks top 10,000 feet (3,000 meters. In the Owen Stanley Range, many peaks reach 12,000 feet (3,650 meters).

Major Water Bodies. New Guinea is in the South Pacific Ocean, which borders the northwestern coast of the island. The northeast coast faces the Bismarck and Solomon Seas. The Coral and Arafura Seas lap the southern coast. The extreme northern tip of the island is nearly cut off from the main island by the approximately 100 mile (160 km) long Berau Bay. On the northwest coast, the Sarera Bay takes a large bite from the island. On the southeast coast, a half-circle area is occupied by the Gulf of Papua.

Rivers, Lakes, And Drainage. New Guinea is bisected by mountain ranges, which are drained by hundreds of small, very swift streams and rivers that feed larger rivers. Most of the major rivers are navigable for 100 miles (160 km) or more inland from their mouths. In Irian Jaya, two large rivers, the Tariku and the Taritatu drain the north slopes of the Sudirman

Range. These two rivers are tributaries of the Mamberamo River. It is over 500 miles (800 km) long, and its mouth is on the South Pacific Ocean. The Digul River rises on south slopes near the east end of one of the subranges of the Sudirmans. It is over 400 miles (640 km) long. It flows south and west to empty into the Arafura Sea at Cape De Jongs.

There are numerous lakes in the lowland drainage plains and swamps and lower valleys of the mountain ranges. One of the larger is Lake Rombebai, near 1°50’ S, 137°55’ E. Lake Sentani, near 2°30’ S, 140°30’ E, is in a wide valley between mountain ranges. Lake Paniai is centered at 3°50’ S, 136°20’E in a deep basin near the western end of the highest peaks of the Sudirman Range.

The mountain ridges in Papua New Guinea are drainage divides for numerous rivers and streams. The Sepik River has its headwaters in the eastern end of the Sudirman Range in Irian Jaya. It is also feed by rivers which flow down the northern slopes of the Bismarck Range. It is 600 miles (970 km) long. The Sepik flows generally east, then empties into the Bismarck Sea. The Ramu River flows northwest and north for 400 miles (640 km) from the Bismarck Range to the Bismarck Sea. The Markham River rises on the south slopes of Finisterre Range. It flows south and southeast to empty into Huon Gulf on the eastern end of New Guinea.

The Fly River is one of the largest rivers on New Guinea. It flows 650 miles (1,046 km) south and southeast to the Gulf of Papua. Its middle course forms part of the boundary with Irian Jaya. The Kikori River flows southeast for over 200 miles (320 km) from its headwaters on the southern slopes of the Bismarck Range. It flows into the Gulf of Papua. The Purari River rises on the south flanks of the Bismarck Range. It flows 170 miles (270 km) southeast to empty into the Gulf of Papua east of the Kikori. Lake Murray is a large, shallow lake in the middle of the extensive alluvial plain of southern New Guinea. It is 15 miles wide by 40 miles long (24 by 64 km). Chambri Lake is in the broad river valley between the north coast mountains and the Bismarck Range.

MAJOR CLIMATIC CONTROLS.

North Pacific High. This high initiates the North Pacific trade winds that dominate the northeast monsoon. As its outflow travels over warm ocean waters, it warms and becomes very moist. This unstable air helps produce large amount of cloudiness and precipitation during the northeast monsoon.

South Pacific High. Outflow from this high creates the South Pacific trade winds. These southerly winds help bring the southwest monsoon.

South Indian Ocean (Mascarene) High. This high’s outflow helps create the Indian southwesterlies, a cross-equatorial flow that is another driver of the southwest monsoon.

Aleutian Low. The Aleutian low acts with the Asiatic (Siberian) high to create a very strong pressure gradient over the western Pacific Ocean. The strength of the pressure gradient directly influences the strength of the winter (northeast) monsoon.

Asiatic High. This thermal high and the Aleutian low create a strong pressure gradient over the western Pacific Ocean, which strongly affects the weather during the northeast monsoon in this area.

Australian High. This thermal high is a part of the belt of high pressure that forms during the Southern Hemisphere winter (the southwest monsoon season). It contributes to the smooth flow of easterlies that characterize this season.

Australian Heat Low. This southern hemisphere summer (thermal) low strengthens the northeast monsoon by increasing the pressure gradient between Asia and Australia. It helps pull the near equatorial trade wind convergence (NETWC) south of the equator.

Near Equatorial Trade Wind Convergence (NETWC). The NETWC marks the boundary between the northeast and southwest monsoon flow. It is created, in part, by convergence of air flow out of the North Pacific and South Indian Ocean highs. At the height of the southwest monsoon, the NETWC is at its northernmost position, and prevailing winds are from a southerly direction in the area. During the northeast monsoon, the NETWC moves south, and the winds are from a northerly direction. These northerly winds produce the annual maximum rainfall during the northeast monsoon in most of the western Pacific basin.

Subtropical Ridges. These are upper-level features found both north and south of the equator. Their mean positions are at 15° N and 10° S, although they move north and south with the sun. Movement south contributes to the wind shift during the establishment of the northeast monsoon, and northerly movement is a factor in development of the southwest monsoon.

Tropical Upper-Tropospheric Trough (TUTT). Because of its strong, upper-level divergence, which is necessary for strong convection, the TUTT is the prime location for tropical cyclone development. During the northeast monsoon, tropical disturbances and cyclones develop under the TUTT north of Australia and move westward. These storms occasionally bring extensive cloud cover and heavy rains to the southern coasts of the Lesser Sundas (Tanimbar) and as far east as the Aru and Kai Island groups. The southwest coast of New Guinea may also feel some of the impact of these storms.

Tropical Easterly Jet (TEJ). The TEJ's mean position is near 15° N, 4-5 degrees south of the surface NETWC. The jet is a Northern Hemisphere summer feature that helps produce southwest monsoon rains in southern New Guinea, the easternmost islands of the Lesser Sundas, and Ceram, Buru, and Sulu islands in the Moluccas. These areas, opposite of much of the rest of the area, receive their maximum rainfall during the southwest monsoon.

Tradewind Inversion. The inversion is present year-round in both the northeast and southeast trade winds. The North Pacific high is characterized by a strong inversion on its southeast quadrant at 6,000-10,000 feet and is stable and relatively dry aloft. The air flowing from the South Pacific high is also stable and dry aloft. An inversion is sometimes apparent at 8,000-10,000 feet, separating the moist and dry air in the air stream. As these air streams converge and create the NETWC, they become more unstable and the inversions weaken significantly.

SPECIAL CLIMATIC FEATURES.

Tropical Waves (Easterly Waves). During the northeast monsoon, when the NETWC is most active, periodic wavelike disturbances are generated in the northeast trades in a narrow belt just north of the NETWC. As these waves deepen and move west, they generate thick, mid-level clouds, followed by a nearly continuous wall of cumulonimbus clouds. The wall of clouds may extend 50-80 miles (80-130 km) in width and 200-400 miles (320-640 km) in length. Surface winds shift to a southeasterly or easterly direction, and gusts may reach 35-45 knots. With a deep, well-developed easterly wave, many areas in the region receive their heaviest rainfall and most severe weather.

Convergence Zones. Topographical features in this area strongly influence weather. On New Guinea, during the southwest monsoon, strong wind flow from the southeast is divided by high mountain ranges. The air flows along both sides of the mountains, then converges at the west end of the island. This convergence of warm, moist air produces a line of cumulus and cumulonimbus in the Ceram Sea that often extends east-west across the full length of the sea. The clouds reach their maximum development before dawn and have winds of 15 knots or more. Similar convergence zones occur on the north arm of Celebes with westerly winds and at the north end of Makassar Strait between Celebes and Borneo with strong southeasterly flow.

Special Climate Features

Another type of convergence zone results because of nocturnal outflow of cool air from the mountains onto the warmer sea. These conditions generally occur with light winds and clear or nearly clear skies. When this cool air meets the prevailing wind flow, it lifts the warmer air and produces lines of cumulus clouds that often develop into cumulonimbus by daybreak. The clouds dissipate during the morning. This type of convergence zone is prevalent off the west and north coasts of New Guinea under light, northeasterly flow. It also causes early morning rainshowers and thunderstorms along the south coast of Ambon during the southwest monsoon. Cooler air flows down the mountains near the coast of the island, lifts the warm air over the ocean and convective clouds develop.

Equatorial Westerlies. This westerly flow originates in the South Indian Ocean high along the African coast. It extends east to 130° E. It is strengthened during the southwest monsoon by outflow from the Australian high. These westerlies bring cool, subsiding air into the monsoon flow, and may contribute to formation of a temperature inversion in the trade winds.

Trade Wind Belts. Outflow from the North Pacific and South Pacific highs produces bands of easterly winds (called trade winds) between 20° N and 20° S. The two easterly moving air streams collect moisture as they pass over the warm ocean waters and bring additional maritime tropical air into the western Pacific basin. The southeast trades (originating in the South Pacific high) cause heavy rainfall during the southwest monsoon in parts of the area, including southwest New Guinea, southern Ceram and Halmahera, the Sula Island group and northeast Celebes.

Land/Sea Breezes. Because of intense heating, the sea breeze may overwhelm the overall synoptic wind circulation in some areas. Some of the smaller islands in the area do not have enough land mass to produce sea breezes. At night, cooler air flowing down the steep mountains creates strong land breezes in some areas. Where the land breeze is funneled by topography, it may reach destructive speeds. On the low, flat coastal plains of some of the islands, the land breeze is very weak, and calm winds occasionally occur. This is common on the broad coastal plains of southern New Guinea.

Valley/Slope Winds. Many of the mountain ranges in this area are cut by deep rift valleys. During the day, up-valley winds may reach 10-15 knots. At night, the down-valley wind is lighter, generally 7 knots or less. Slope winds occur when mountain faces heat and cool faster than surrounding lower areas. During the day, up-slope winds are usually 6-8 knots. Winds are strongest on slopes facing the sun. Down-slope winds are usually 4-6 knots. Very steep slopes will produce stronger winds, but they seldom exceed 8-9 knots.

Foehn Winds. These hot, dry, damaging winds are most common on Celebes. Foehns occur in other places, but usually with a less impact on crops.

Mesoscale Convective Complexes (MCCs). MCCs are massive collections of cumulonimbus cells topped by mesoscale mid- to upper-level stratiform and anvil clouds. MCCs usually begin to develop near midnight, when the land breeze converges with warm, low-level monsoon flow over the water. Until early morning, when the stratiform and anvil clouds are formed, the rain is mostly heavy showers. A few hours after sunrise, most of the precipitation is continuous rain from stratiform clouds. As the land mass heats and a sea breeze develops, convergence ends and convective clouds dissipate. The mid level stratiform clouds dissipate also, while the higher anvil clouds slowly expand horizontally. MCCs are common off the northwest coast of New Guinea.

Tropical Cyclones. This area is too close to the equator to experience the full brunt of tropical cyclones. On rare occasions, usually in November or December, a tropical storm (winds of 35-64 knots) may pass north of Halmahera on a west or northwest track across the Celebes Sea. Also rarely, duringMarch or April, a storm may pass south of Tanimbar and cross the Arafura and Timor Seas. Since these storms are in their formative stages, destructive winds seldom occur, but thick, low clouds, heavy rains and high seas usually accompany their passage.

El Niño. This is an event that usually begins in December and is characterized by unusually cool water temperatures in the western Pacific. The colder water suppresses convective activity. At the same time, the North Pacific high intensifies and covers a larger area than usual. Southward expansion causes the NETWC to move closer to the equator. Monsoon flow is disrupted in both seasons and precipitation diminishes in the area. In severe cases, drought becomes dangerous.

La Niña. This event is the opposite of El Niño. During the La Niña cycle, the waters surrounding the area are warmer than usual. This helps create more cloudy conditions, and heavier than normal rainfall. Flooding is much more likely during this period because of the heavy, prolonged rain.

Seasons. Celebes, the Moluccas, and New Guinea are in the Southern Hemisphere except for the north peninsula of Celebes and the northern three-fourths of Halmahera in the Moluccas. The area experiences "summer" temperatures all year, so temperature cannot be used to define the seasons. A seasonal reversal of the prevailing winds (a monsoon) occurs, caused by changes in the major semipermanent weather systems. During the months of November through April, the winds are predominately from a northerly direction. They may vary from northwest to northeast depending on location. In May through October, the winds are from a southerly direction, which varies from southeast to southwest. For convenience, the monsoon seasons are called the northeast monsoon and southwest monsoon.

Topography. Topography is one of the most important influences on the weather in this area. The terrain varies from low, flat, swampy plains and savannas to towering mountain ranges that rise abruptly from the sea on many of the islands. In central New Guinea, the mountains reach 15,000 feet (4,600 meters), with even higher isolated peaks. The lowest areas rarely see temperatures below 60° F (16° C). Windward slopes are the cloudiest and receive the most precipitation, while the lee sides of the mountains experience much less cloudiness and rainfall. In some valleys sheltered from the monsoon winds, precipitation is relatively sparse. Other areas, exposed to the full monsoon winds, receive vast amounts of precipitation. Because of the sheltering effect of some mountain ranges, the wettest period may be in entirely different months, or even seasons, on opposite sides of the mountain ranges. Intense surface heating generates a sea breeze along the coasts. The breeze is often strong and may overwhelm the large scale monsoon flow. Cooling of mountain slopes near coasts at night generates land breezes. Funneling through valleys or passes may cause the breezes to be quite strong. Because of the ruggedness and variety of the terrain and its effects, the large scale monsoon patterns are more pronounced over the surrounding waters than on the land areas of the region.

Northeast Monsoon: November - April

General Weather. November is generally a transition period between the southwest and northeast monsoons. During November, the NETWC begins to move south. By January, its mean position is near 5° S. Wind flowing out of the North Pacific high is dry, stable and characterized by a strong temperature inversion. The air warms and becomes very moist as it travels across the vast expanse of the ocean. This warm, moist, unstable air converges with outflow from the South Indian Ocean and South Pacific highs to create the NETWC. This convergence produces considerable cloudiness, heavy rainshowers, and strong thunderstorms throughout the area. As the airstreams converge, the air becomes more unstable, and the temperature inversion weakens, but is still evident at 6,000-10,000 during much of the season. By the end of April, the transition to the southwest monsoon begins.

Mean cloud cover is often 50 percent or more during the northeast monsoon. Except with afternoon thunderstorms, the cloud cover is generally stratocumulus with some small cumulus clouds. The tradewind inversion tends to cap clouds not produced by orographic lifting. The most severe weather, heaviest rainfall and lowest ceilings and visibility are caused by easterly waves that periodically move through the area just north of the NETWC.

Sky Cover. Sky cover generally follows a predictable diurnal pattern during the northeast monsoon. Cloudiness is greatest during the afternoon and early evening and on windward slopes of mountain ranges. In most locations, January is usually the cloudiest month. At dawn, only scattered middle clouds may remain in lowland coastal areas. Over inland swampy areas and elevated basins, thin, low stratus and patches of fog are common. By 0900L, these dissipate and cumulus clouds develop. In the lowlands, cumulus clouds increase to maximum development by early afternoon, when rainshowers and thunderstorms begin. By late afternoon, the cumulus clouds begin to dissipate, and are usually gone by dark. Over the mountains, the cumulus clouds continue to grow during the afternoon and reach peak development in late afternoon. The thunderstorms move down the mountain slopes, produce heavy rainshowers and move out to sea. Clear or scattered conditions prevail for the rest of the night in low areas. On the higher ridges, layered low clouds may persist throughout the night.

Ceilings below 10,000 feet occur up to 26 percent of the time during November, up to 31 percent of the time in January and as often as 36 percent of the time in April. One station, Ambon, on the south coast of a small, mountainous island south of Ceram, is sheltered from the northeast flow, and is less cloudy during the northeast monsoon. Ambon experiences ceilings below 10,000 feet up to 7 percent of the time in November, 13 percent of the time in January, and 15 percent of the time during April.

The opposite exception is on the south coast of a peninsula that extends from western Irian Jaya into the Ceram Sea. This area is backed by steep mountain ridges. Here, ceilings below 10,000 feet occur nearly 40 percent of the time throughout the northeast monsoon. Other areas with similar terrain and orientation have similar conditions. Sites in the mountains have ceiling is below 10,000 feet at much as 80 percent of the time.

Ceilings below 3,000 feet are not common in this area. They occur most often during and after afternoon thunderstorms. During November, the ceiling is below 3,000 feet from 2 to 16 percent of the time at most stations. In January, they occur up to 25 percent of the time and up to 26 percent of the time in April. Ambon reports this ceiling infrequently, less than 5 percent of the time throughout the season. Windward, high mountain sites have ceilings below 3,000 feet up to 75 percent of the time during the northeast monsoon.

Ceilings below 1,000 feet or below 500 feet are rarely observed, except for 1 or 2 hour periods with rainshowers or thunderstorms. Windward, high mountain sites have ceilings below 1,000 feet up to 38 percent of the time, and less than 500 feet 20 percent of the time.

The usual diurnal cloud cover pattern does not hold true in the broad alluvial plain of Irian Jaya at the southern base of mountains that line the coast very near the border with Papua New Guinea. Drainage winds flow down the mountain slopes during the night and early morning hours. The air warms as it descends, which creates a small scale "dry line" front. The drier air lifts the unstable, very moist air over the swamps and lakes, and convection develops. Ceilings below 3,000 feet occur nearly 40 percent of the time between midnight and dawn. Lower ceilings occur infrequently. See Figure 5-3.

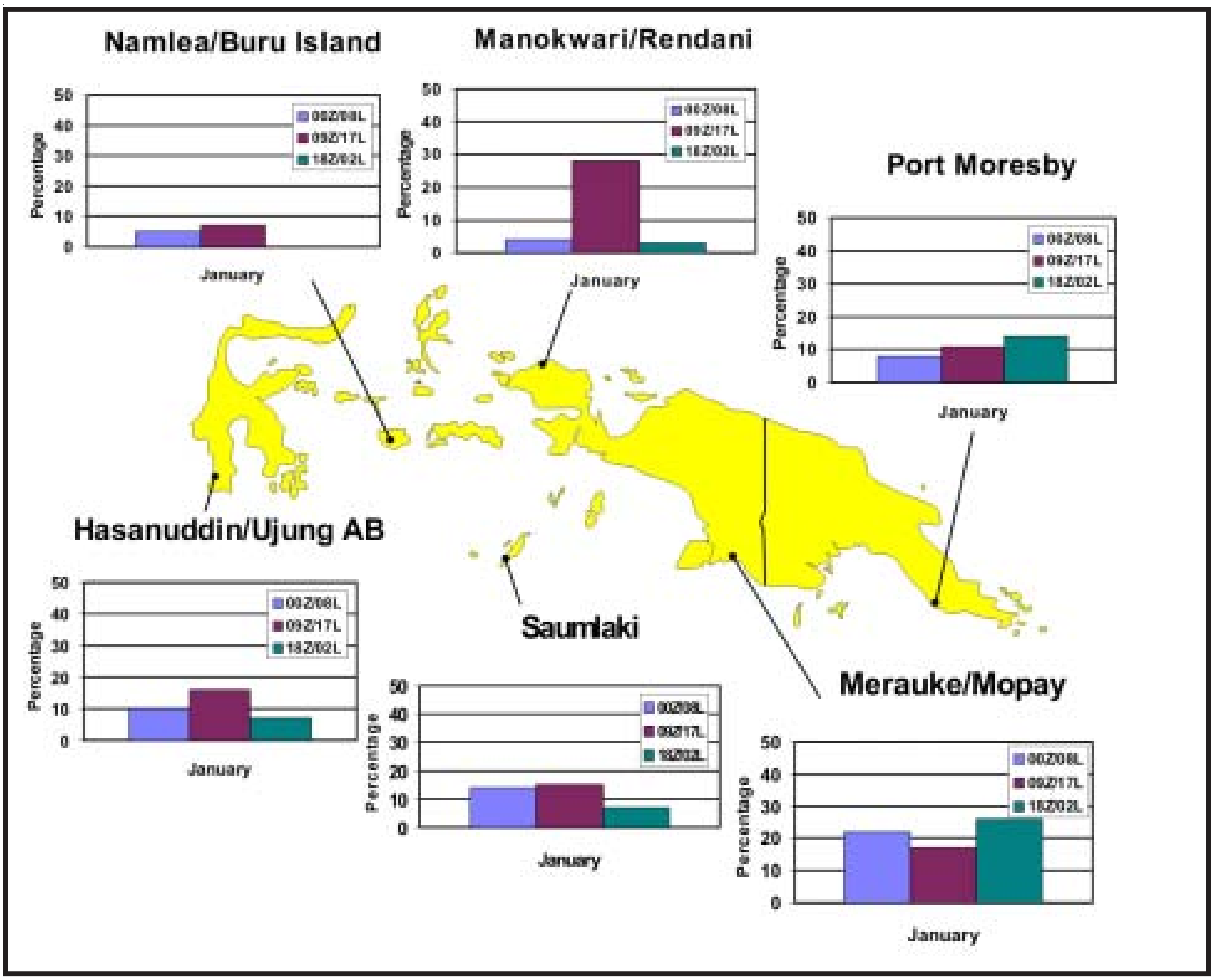

Figure 5-3. Northeast Monsoon Percent Frequency of Ceilings below 3,000 Feet for November to April. The graphs show a monthly breakdown of the percent frequency of ceilings below 3,000 feet based on location and diurnal influences.

Northeast Monsoon: November - April

Visibility. Although visibility is generally unrestricted during the northeast monsoon, afternoon thunderstorms with heavy downpours can reduce visibility significantly, at times to near zero, for short periods. These thunderstorms are common on the windward slopes of mountains so areas in the monsoon flow will experience more visibility restrictions than those in the lee of the flow. In low, marshy areas, river valleys, and upland basins, early morning ground fog may reduce visibility to 3 miles (4,800 meters) or less. The fog dissipates shortly after sunrise. If the advent of the northeast monsoon is delayed, especially after an unusually dry southwest monsoon, smoke from fires may cause some visibility restrictions in the early season. This is most common on Celebes. When monsoon rains begin, the air clears and visibility increases.

Visibility is less than 3 miles (4,800 meters) 7 percent of the time or less at most locations (Figure 5-4). These restrictions occur equally in all months of the northeast monsoon, and slightly more often during the afternoon. In large, low, drainage plains the restrictions occur more often, up to 10 percent of the time. On the northeast coast of Bone Bay on Celebes, the visibility is less than 3 miles as much as 20 percent of the time.

Most stations in the area experience visibility below 1 mile (1,600 meters) a maximum of 4 percent of the time (Fak-Fak) and as seldom as less than 1 percent of the time. Visibility below one-half mile (800 meters) is very rare. During heavy rainshowers, the visibility may drop to near zero for brief periods, then increase rapidly when the storms pass. Visibility data for high mountain stations is very limited. Ground fog frequently forms before sunrise in high valleys and basins, so visibility is most likely restricted to less than 4,800 meters during the early morning hours. The fog will lift to form low stratus ceilings after sunrise, as reflected in the frequency of low ceilings at this station.

On the north coast of Irian Jaya, near the border with Papua New Guinea, nocturnal rainshowers reduce visibility to less than 4,800 meters 66-83 percent of the time, most often in January. The visibility drops below 1,600 meters 14-24 percent of the time, and below 800 meters 2-7 percent of the time.

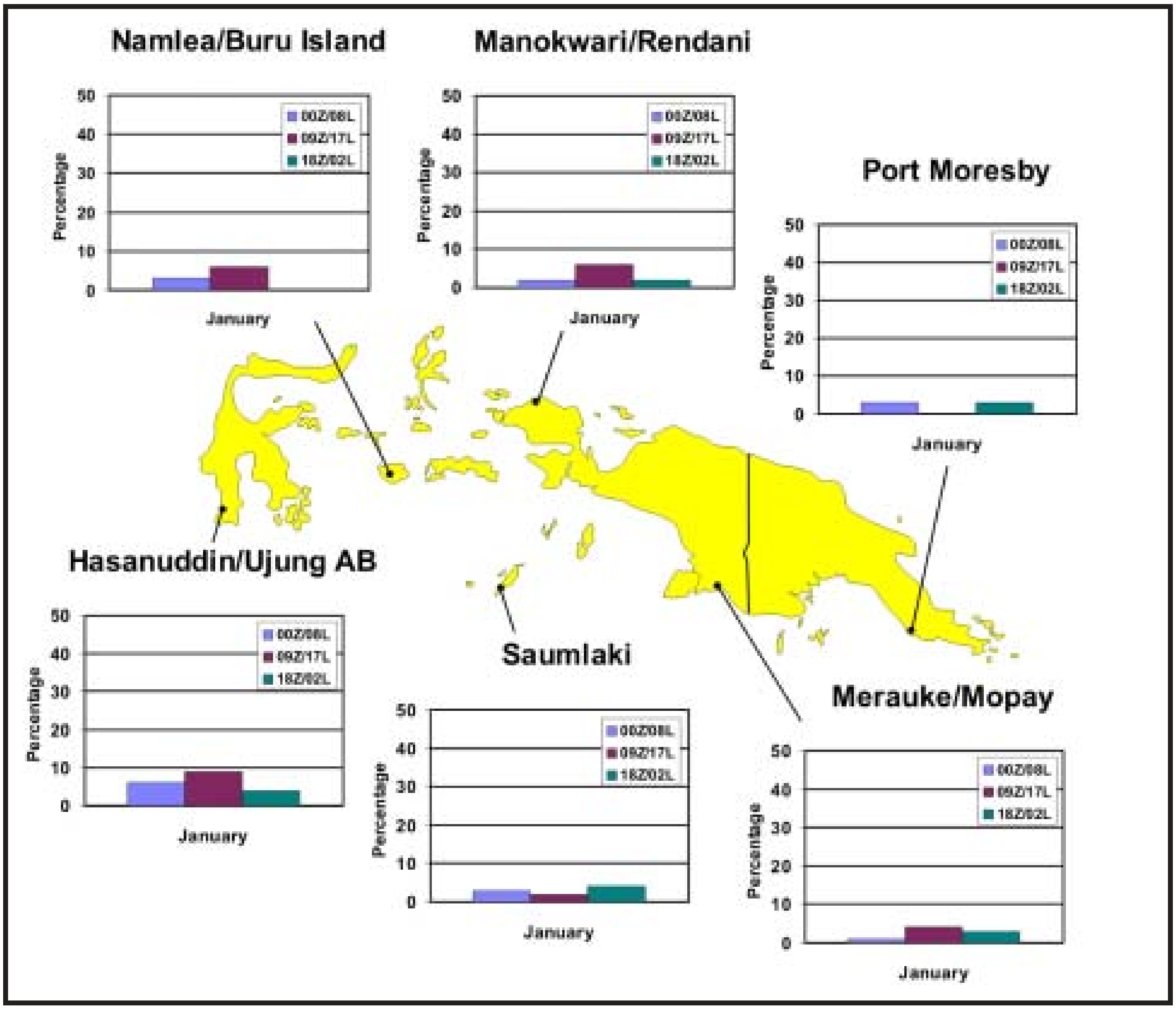

Figure 5-4. Northeast Monsoon Percent Frequency of Visibility below 3 Miles (4,800 Meters) for November to April. The graphs show a monthly breakdown of the percent frequency of visibility below 3 miles based on location and diurnal influences.

Northeast Monsoon: November - April

Surface Winds. Winds are generally from a northerly direction. Winds at any one location are strongly influenced by terrain in mountainous locations, and by land/sea breezes at coastal stations. The monsoon wind direction varies from northwest to northeast, with the southernmost stations experiencing a more westerly direction. Wind speeds are light, usually 5-10 knots (Figure 5-5). Most stations have reported much stronger winds during thunderstorms, as high as 75 knots, with some wind gusts over 90 knots. These unusually strong thunderstorm gusts generally occur in the transition to the southwest monsoon in April or May, when the weather is most violent and variable. Along the north coasts of larger islands, the afternoon sea breeze may reinforce monsoon flow, and raise winds to 15 knots.

At some places where mountain valleys reach the coast, very strong local winds may occur. The best known of these is the *guba*, a foehn that occurs 4-5 times a year during early morning at Port Moresby in Papua. The winds rush down the valley at 50-60 knots for 20-30 minutes. Port Moresby is on the lee side of the Owen Stanley Range during the northeast monsoon, so the guba is more frequent during this season.

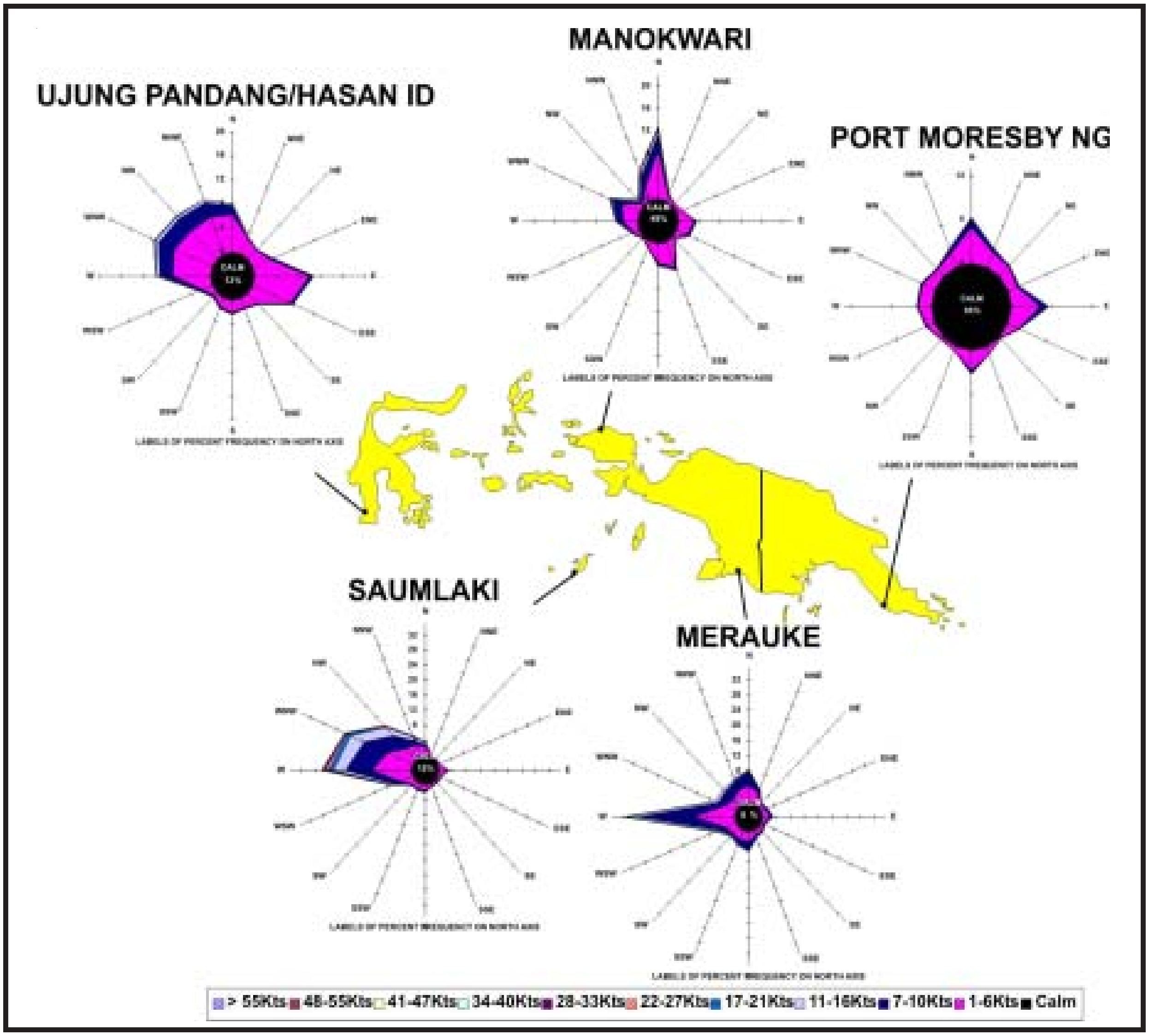

Figure 5-5. January Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Air Winds. The islands in the western Pacific basin are overlain by 3 wind systems. The lowest is the monsoon current. The northeast monsoon prevails with a more easterly flow to 8,000 feet north of the equator. South of the equator, a pronounced westerly flow prevails to 20,000 feet. Above the monsoon flow and up to 300 mb, the maximum wind speeds are generally 55-60 knots in January. Above that and below the tropopause, a band of persistent tropical easterlies flows. Wind speeds increase with height, to a mean maximum of 35 knots at 45,000-50,000 feet in January. Above the easterlies are alternating layers of persistent easterlies and westerlies between 60,000 and 80,000 feet that may reach speeds above 100 knots. See Figure 5-6.

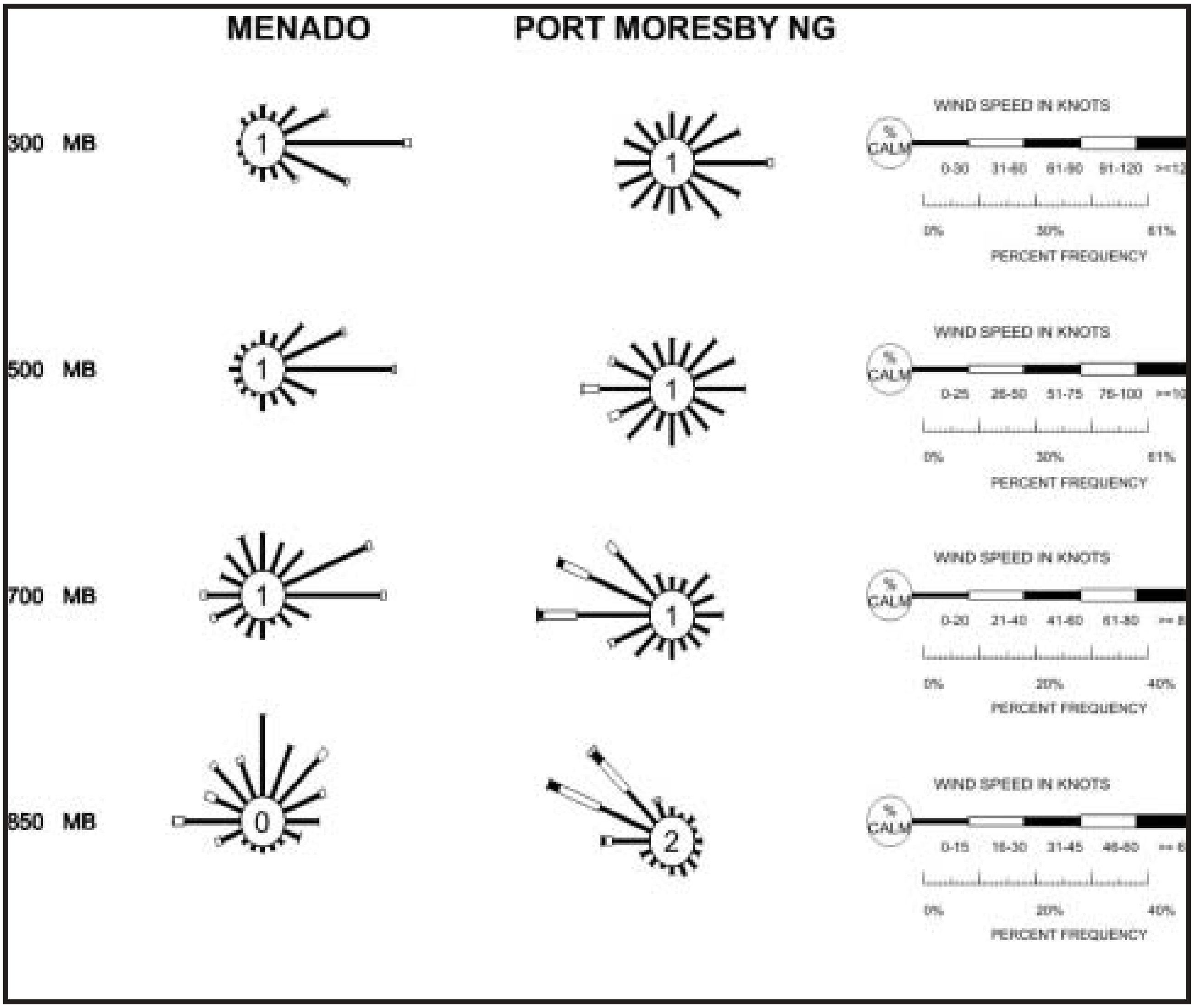

Figure 5-6. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at two locations, one north and one south of the equator.

Northeast Monsoon: November - April

Precipitation. Rainfall is heavy and frequent in most of the area during the northeast monsoon. Frequent afternoon thunderstorms account for most of it. Rainfall is greatest at locations directly windward to northeast monsoon winds. Port Moresby, in the rain shadow of the Owen Stanley Range, gets rain an average of 68 days all season, much less than other stations where it rains well over 100 days during the season. Ambon, in the central Moluccas, is somewhat sheltered from the northeast monsoon winds by mountains. It receives considerable rainfall now, but its wettest period is during the southwest monsoon when it is fully exposed to the wind flow. Jayapura, contrary to the afternoon maximum rainfall in most of the area, receives its maximum rainfall between midnight and dawn. This is caused by “dry line” convection. See Figure 5-7.

Overall, the wettest months in Celebes are March and April. In the Moluccas, the central mountains of Halmahera receive maximum rainfall in April-June. On the north coasts of the central islands, the wettest period is January-March. On the south coasts, this is the driest (least wet) period. In the southern islands, December-April is the wettest period. In Irian Jaya, the wettest period is December-March near the north and south coasts. On the southern (lee) slopes of the mountains, this is a dry period. In the remaining areas, the most rain falls in April-June. The precipitation regime in Papua New Guinea is very similar to that in Irian Jaya. Kikori, in southern Papua very near the Gulf of Papua, is very wet during the northeast monsoon, but it experiences the full force of the southwest monsoon so the northeast monsoon relatively drier.

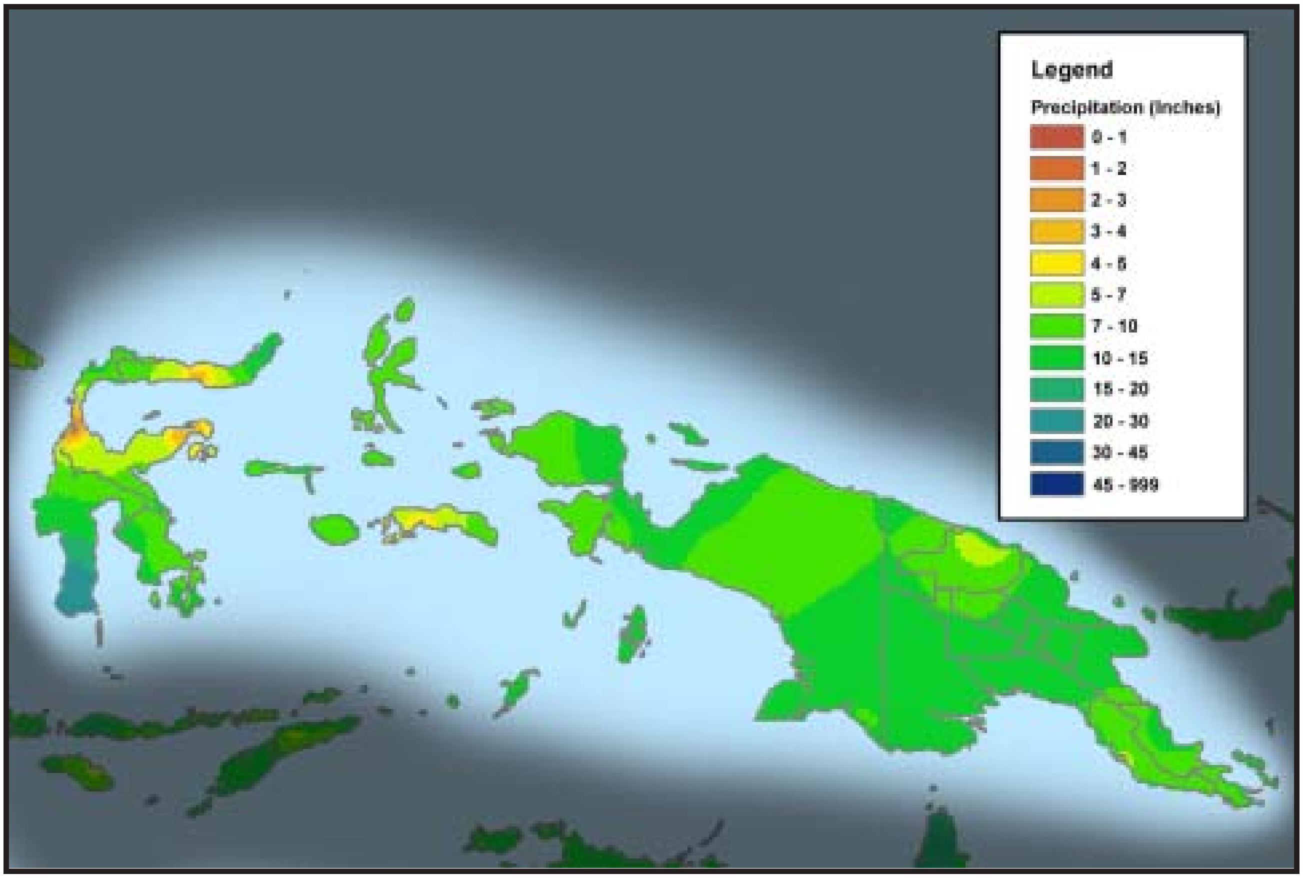

Figure 5-7. January Mean Precipitation. The figure shows mean precipitation in the region.

During the northeast monsoon, January is the wettest month at most locations. It rains 13-25 days. Stations in the lee of the monsoon flow experience the fewest rain days. During April, when the transition to the southwest monsoon begins, rainfall days increase at these stations, since they become windward. Most areas experience fewer rain days in November, the transition period from the southwest to the northeast monsoon season. See Figure 5-8.

The number of thunderstorm days ranges from 18 in December and January at Madang, to only 1 day in January and February at Menado. Madang, on the north coast of Papua, is directly in the monsoon air flow. Menado is in a basin, at the east end of Celebes' north peninsula, sheltered from the monsoon wind. Rain days are greater than thunderstorm days. Often, cumulus will develop enough from orographic lift or afternoon heating to produce rainshowers but not thunderstorms..

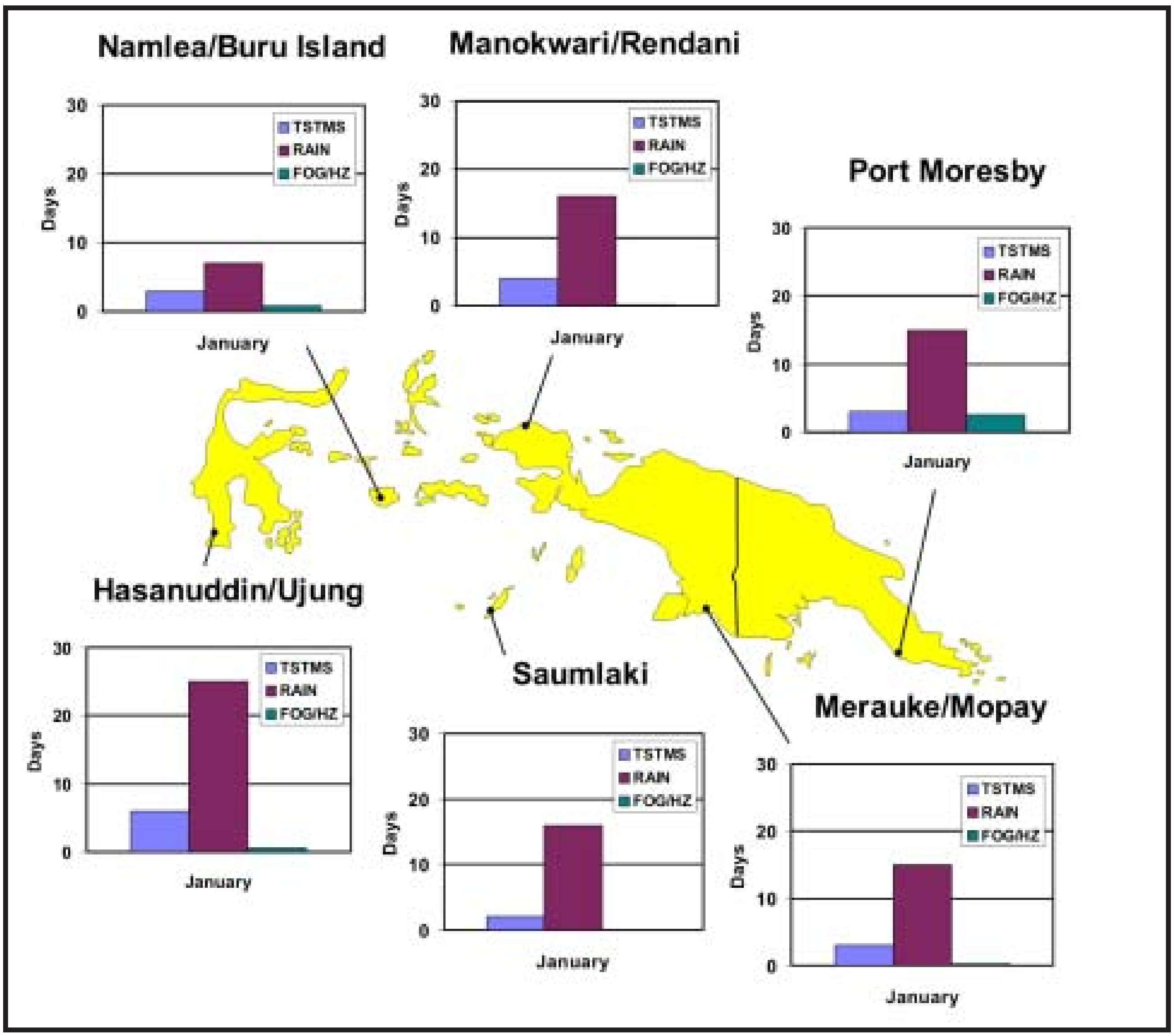

Figure 5-8. Northeast Monsoon Mean Precipitation and Thunderstorm Days, from November to April. The graphs show the average seasonal occurrences of rain and thunderstorm days for representative locations in the region.

Northeast Monsoon: November - April

Temperatures. Temperatures in the area are remarkably uniform at lower elevations. The daily temperature ranges are greater than the annual ranges. The difference between the daily mean highs and lows is 10-15 Fahrenheit (6-8 Celsius) degrees. The diurnal ranges are less at coastal stations due to the moderating influences of the warm ocean waters. Mean highs are 82° to 86°F (28° to 30° C) except on small islands in the Moluccas. Mean highs there are 86° to 90°F (30° to 32° C). Mean lows are 73° to 81°F (23° to 27°C). Sattelburg Mission, at 3,000 feet (900 meters) on the tip of a peninsula that extends into the Solomon Sea, reports lower temperatures. The January mean high is 81° F (27° C) and the mean low is 68° F (20° C). During the day, on-shore winds that flow up the steep mountain slopes bring heavy cloud cover to the station and keep the temperature lower than many other stations. At night, downslope winds clear the clouds and radiation cooling reduces the temperature. Wamena, in a sheltered basin, reports a January mean high of 73° F (23° C) and a mean low of 68° F (20° C). Temperatures decrease with height at the moist adiabatic lapse rate (3 Fahrenheit or 1.6 Celsius degrees) per 1,000 feet (300 meters). Freezing temperatures occur only at elevations above 10,000 feet. Temperatures in the area rarely reach the upper 90s F (mid to upper 30s C), although readings of 100° F (38° C) or higher have been reported. These extreme temperatures are caused by foehns. See Figures 5-9 and 5-10.

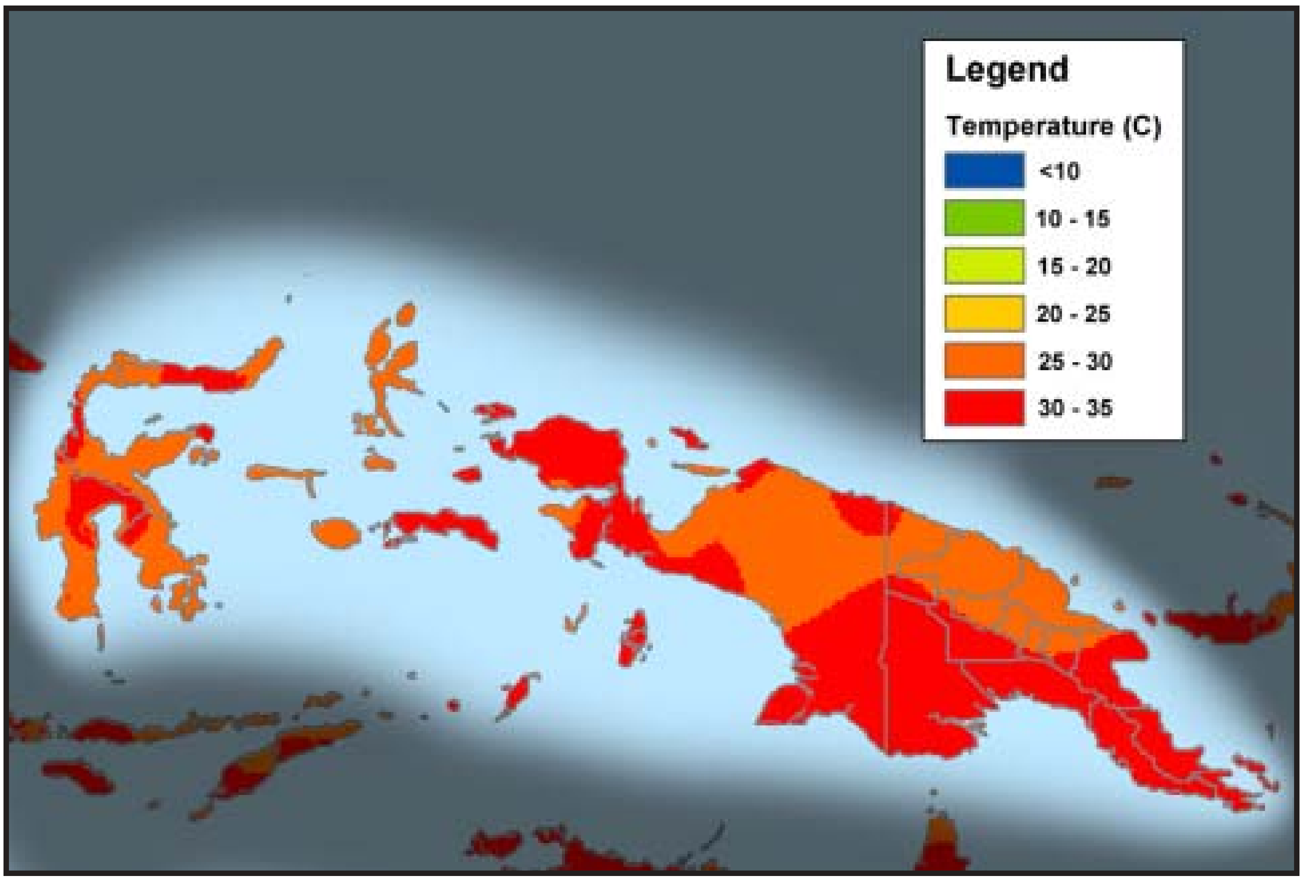

Figure 5-9. January Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the month. Daily high temperatures are often higher than the mean.

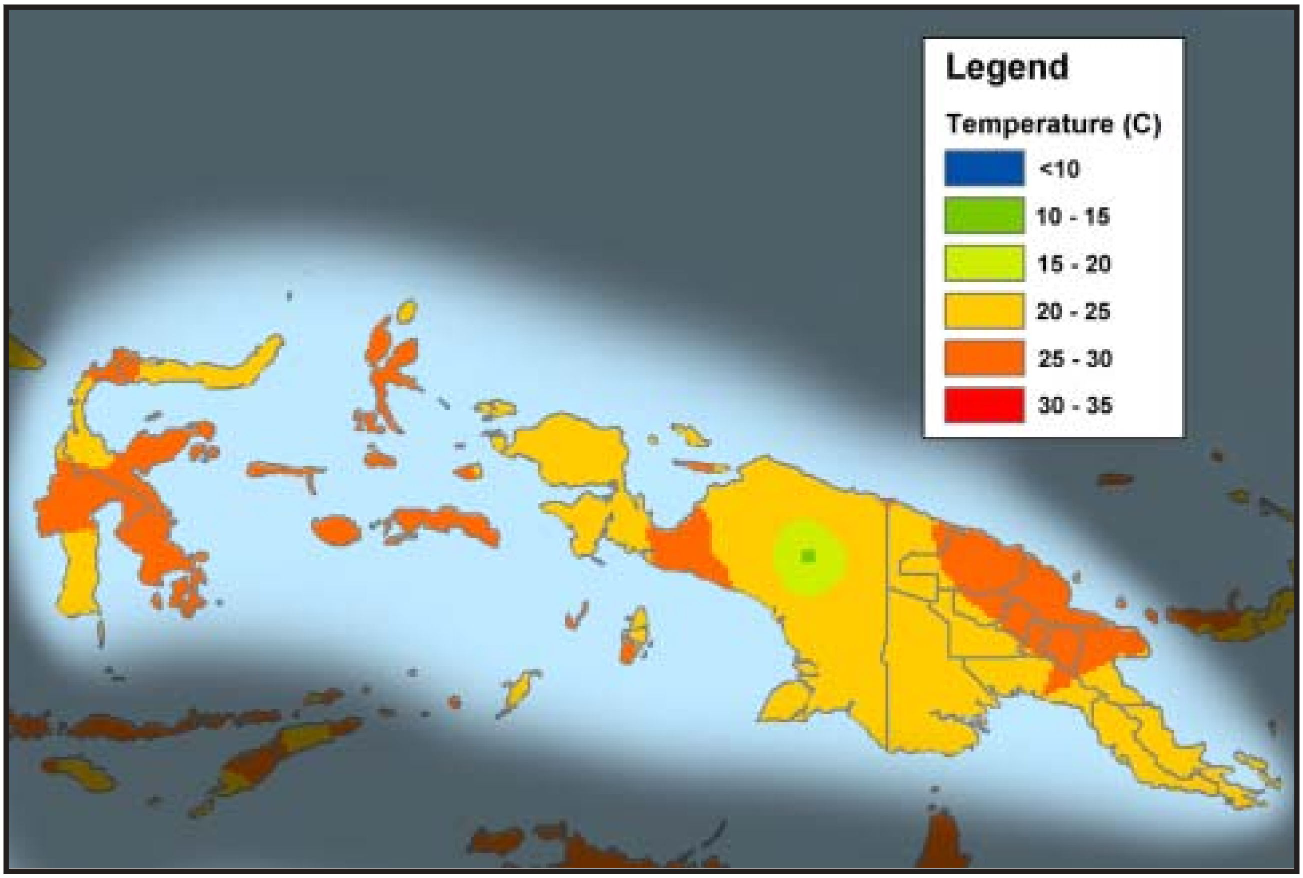

Figure 5-10. July Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the month. Daily low temperatures are often lower than the mean

Hazards. Vast amounts of rain fall in short periods of time. Many rivers frequently overflow their banks, flood entire valleys and spread over vast areas of lowland areas. Roads wash out completely or become impassable because of deep water. Tropical thunderstorms develop to towering heights, often 50,000 feet or more. In addition to heavy downpours, the storms create strong downrush gusts on the surface and violent up and down drafts within the clouds. Severe turbulence occurs in, near, and under the storm clouds. Lightning from the storms is frequent and can be deadly. Strong surface heating will create updrafts and thermal turbulence in the area. The turbulence may reach the moderate category. Winds blowing across mountain ridges will produce moderate to severe mountain wave turbulence over the ridges and up to 50 miles (80 km) downwind. The freezing level is at 15,000 feet in this area. From the surface to this altitude, icing is not a threat. Between 15,000 and 25,000 feet (the mean height of the 20° C isotherm), icing becomes a serious threat. Clouds between these levels will produce clear and/or rime icing. The heat and humidity in the area can be dangerous. Dehydration, heat stroke and sun stroke can be significant hazards.

Trafficability. Heavy rains reduce roads to mud, swamp lowland areas, and destroy structures. These conditions will seriously impact trafficability. Undergrowth in dense rain forest jungles and in forests on mountain slopes can make off-road movement impossible.

Southwest Monsoon: May-October

General Weather. The transition to the southwest monsoon usually begins in late April and continues through May. This transition season is generally marked by unsettled weather with violent thunderstorms and heavy rains. The NETWC does not move steadily north but oscillates north and south depending on the relative strength or weakness of the North Pacific and South Pacific highs. By July, the NETWC settles well north of the area, near 10°-15° N. The winds are now from the south. This airflow comes from the South Pacific, Australian (thermal) and South Indian Ocean highs. It has a much shorter fetch over warm water, so it is much drier (or less moist), and more stable than the northeast monsoon airflow. A weak temperature inversion, especially in the outflow of the South Pacific high, is sometimes apparent at 6,000-10,000 feet. Because it is less moist and more stable, cloudiness and precipitation are at a minimum over much of the area. As with most generalized statements, there are exceptions. Air from the South Pacific high travels a considerable distance from its source before reaching the south coast of New Guinea, islands in the southern Moluccas, and the northern peninsula of Celebes. It collects moisture and becomes more unstable on its journey, and produces maximum cloudiness and rainfall in these areas during the southwest monsoon.

Sky Cover. The diurnal sky cover cycle during the southwest monsoon is similar to that of the northeast monsoon, except there are generally fewer clouds, rainshowers, and thunderstorms. The windward slopes of mountains are the cloudiest, while the lee slope experience the least. Outside of thunderstorms and rainshowers, the cloud cover is cumulus or stratocumulus. Thunderstorms are much more widely scattered. Since there are fewer thunderstorms, fewer middle cloud decks develop.

The ceiling is less than 10,000 feet during May up to 20 percent of the time at locations sheltered from the southwest monsoon flow. Ambon, Saumlaki on Tanimbar, and Merauke in southeastern Papua, all windward to monsoon flow, experience this ceiling 30 percent of the time. Fak-Fak reports ceilings below 10,000 up to 72 percent of the time. Wamena, the high valley station in Irian Jaya, reports the ceiling below 10,000 feet nearly 70 percent of the time. July brings an increase in this ceiling at many locations, up to 33 percent of the time. Most stations windward to monsoon flow report the ceiling as much as 50 percent of the time; Fak-Fak experiences ceilings below 10,000 feet up to 86 percent of the time. Wamena has this ceiling 75 percent of the time. Some locations report ceilings below 10,000 feet less often in October, but others still experience it up to 33 percent of the time. At Fak-Fak, the frequency drops to 66 percent of the time and Wamena experiences it up to 73 percent of the time.

In May, the ceiling is less than 3,000 feet from less than 5 percent to 23 percent of the time, slightly less frequently than during the northeast monsoon. Saumlaki and Fak-Fak, exposed to the full southwest flow, experience this ceiling 26 percent and 42 percent of the time respectively. In the high valley at Wamena, the ceiling is less than 3,000 feet 65 percent of the time. In July, ceilings below 3,000 feet occur from as infrequently as almost never up to 26 percent of the time. Fak-Fak has them up to 49 percent of the time, Saumlaki 26 percent of the time and Wamena as much as 73 percent of the time. By October, the frequency of ceilings below 3,000 feet decreases. Most stations report this ceiling up to 20 percent of the time. Fak-Fak has it 45 percent of the time, while Saumlaki again reports it 26 percent of the time. At Wamena, the ceiling is below 3,000 feet 72 percent of the time. Jayapura experiences "dry line" nocturnal convective activity during the southwest monsoon also, although to a lesser degree. Ceilings below 3,000 feet occur up to a maximum of 30 percent of the time between midnight and dawn.

Throughout the southwest monsoon, the ceiling is rarely below 1,000 feet or below 500 feet. The exception occurs in heavy downpours, when the ceiling may drop this low for 1 or 2 hours. Many stations very rarely report these low ceilings. During afternoon rainshowers, Fak-Fak reports a ceiling below 1,000 feet up to 12 percent of the time, most often in May. Wamena reports the ceiling up to 15 percent of the time. Fak-Fak reports a ceiling below 500 feet only 4 percent of the time in July and Wamena experiences it 6 percent of the time in May. Other stations in the area report it rarely. See Figure 5-11.

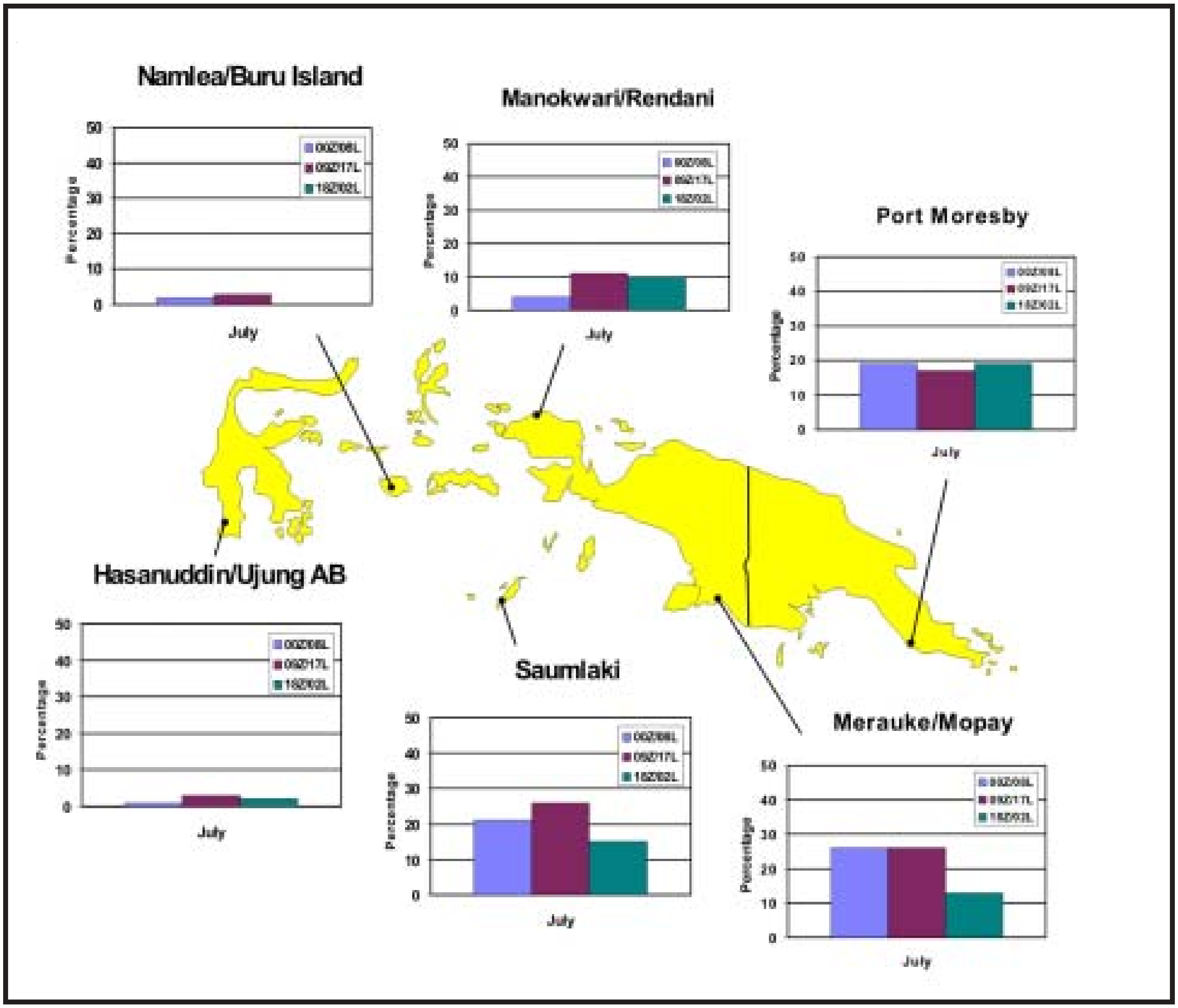

Figure 5-11. Southwest Monsoon Percent Frequency of Ceilings below 3,000 Feet for May to October. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Visibility is generally good. Rainshower and thunderstorm activity occurs less in this season, so visibility is restricted less often by heavy rains. In low, marshy areas, river basins and upland basins ground fog forms in the early morning but dissipates by 0800-0900L. During this relatively dry period, forest fires are a threat. Smoke from fires may persist for many days and reduce visibility to 5 miles (8,000 meters) or less in some areas. Another visibility restrictor is dry haze, especially in the southeastern part of the region. The haze is composed of smoke, dust from Australia and salt particles. During average years, it can reduce visibility to 6-8 miles (9,000 to 12,800 meters). During very dry years, visibility may be reduced to 3 miles (4,800 meters), or even 1 mile (1,600 meters) or less in exceptionally dry periods. The haze is capped by the usual temperature inversion at 6,000-10,000 feet. Above the inversion, the air is clear and visibility is very good. The haze increases in density as the season progresses and persists until the first widespread rains of the northeast monsoon.

At most locations, visibility below 3 miles (4,800 meters) occurs . Most stations experience it a maximum of 10 percent of the time. At Fak-Fak, because of its terrain and location relative to wind flow, the visibility is below 3 miles 24 percent of the time, most often in the afternoon. Jayapura experiences visibility below 3 miles up to 74 percent during its frequent nocturnal rainshowers. Madang on the north coast of Papua, has visibility below 4,800 meters up to 5 percent of the time. Port Moresby, on the south coast of Papua, has visibility below 4,800 meters 4 percent of the time because of its location on the coast. See Figure 5-12.

Visibility is rarely below 1 mile (1,600 meters); however, Fak-Fak gets visibility below 1,600 meters up to 11 percent of the time and Jayapura has it up to 10 percent of the time. Only Fak-Fak reports visibility less than one-half mile (800 meters) outside of convective precipitation. Even here, it is reported a maximum of only 5 percent of the time in early morning fog, which dissipates within 1 or 2 hours.

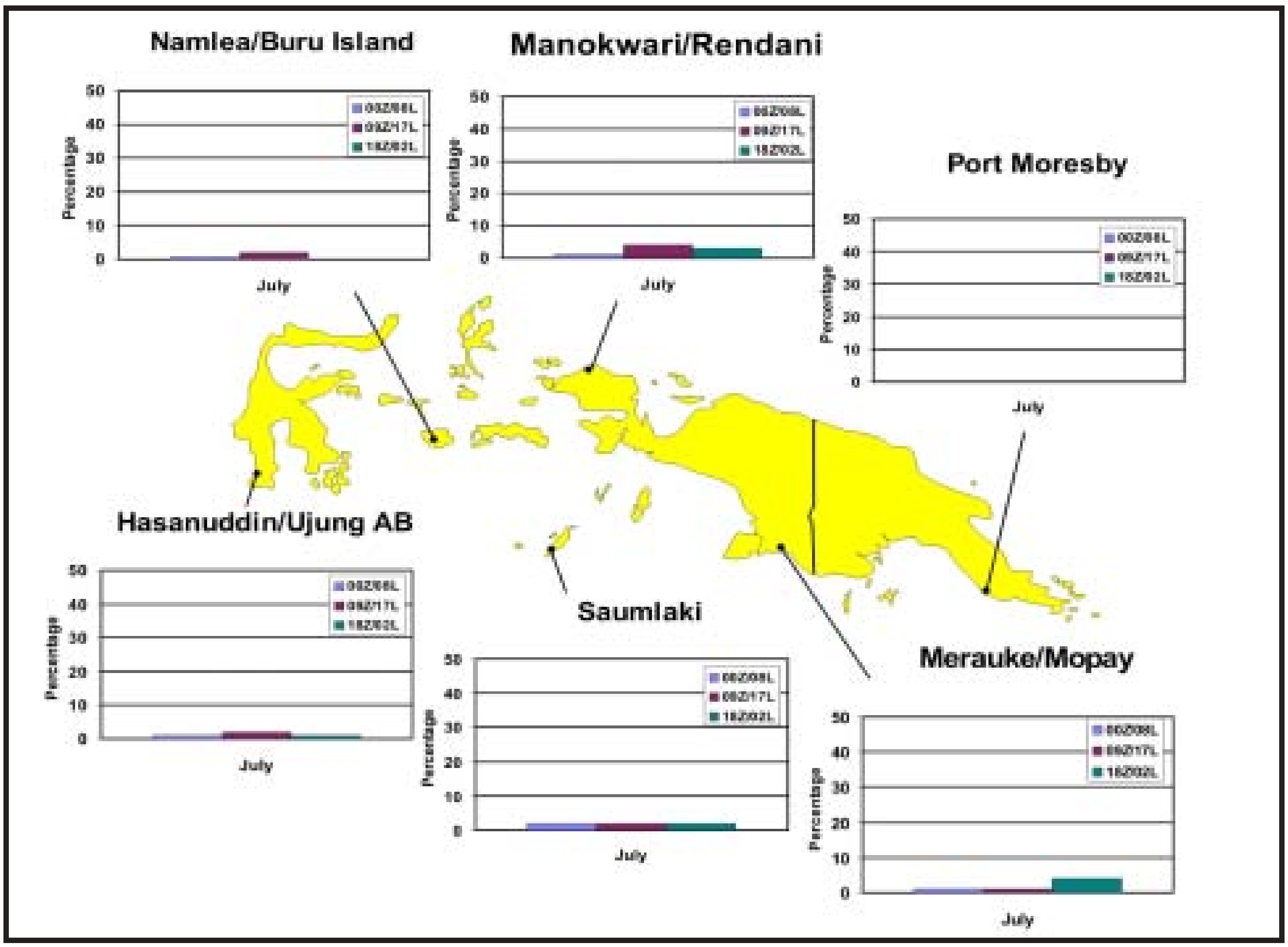

Figure 5-12. Southwest Monsoon Percent Frequency of Visibility below 3 Miles for May to October. The graphs show a monthly breakdown of the percent frequency of visibility below 3 miles based on location and diurnal influences.

Surface Winds. The winds are usually from a southerly direction and are strongly influenced by terrain. In the northern part of the area, winds are from the southeast, south or southwest. In the southern part, winds are usually from the east or southeast. Merauke, on the southeast coast of Irian Jaya, experiences predominantly east winds. At Wamena, the prevailing wind remains southeasterly, except at night, when down valley winds blow from the northwest. Madang is on the northeast coast of Papua, but it experiences easterly winds during the southwest monsoon. It is in an east-west valley between mountain ranges. The southerly wind flow is deflected by the mountain ranges into the valley. Winds are light, usually no more than 10 knots. The drier, stable air of the southwest monsoon results in less convective activity; however, gusts of 50-70 knots have been reported at most stations, and a few stations reported speeds as high as 90 knots.

Port Moresby may experience the strong guba wind if the southwest monsoon flow is disrupted, especially during the early part of the season. It is a rare event, but possible during the southwest monsoon. The southwest monsoon airflow is drier and more stable than the northeast monsoon air, but the southerly flow travels across a long stretch of warm ocean water before reaching the southern coast of New Guinea, the southern Moluccas, and the northeast peninsula of Celebes. These areas receive their maximum cloudiness and precipitation during the southwest monsoon. See Figure 5-13.

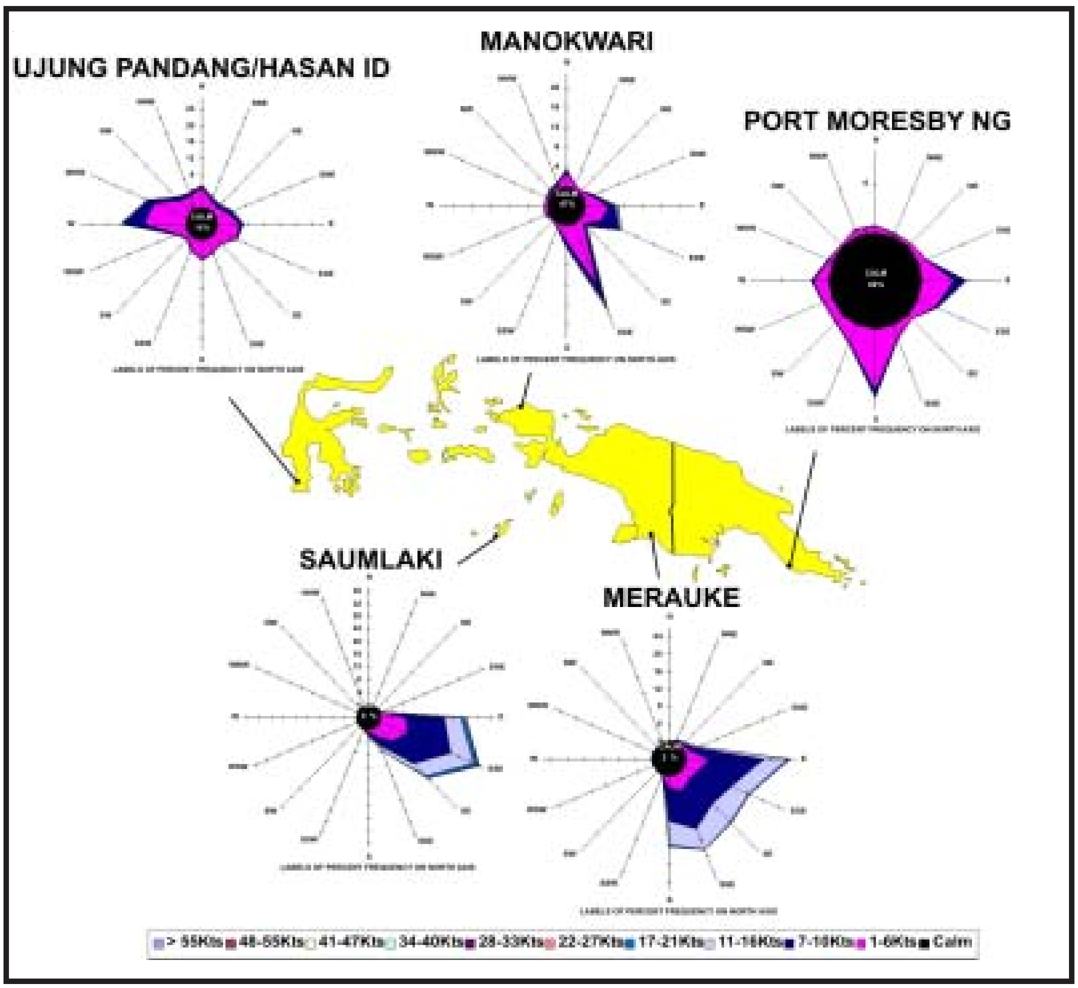

Figure 5-13. July Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Southwest Monsoon: May-October

Upper-Air Winds. The southwest monsoon flow prevails up to 6,000-10,000 feet in most of the area and up to 15,000 feet in the northern part. In the north, the monsoon flow is generally westerly. South of the equator, the winds are easterly. Above the monsoon flow, up to 30,000-35,000 feet, winds are generally easterly. Wind speeds tend to be slightly higher during the southwest monsoon, at times over 60 knots. Above this level and up to the tropopause, the persistent easterlies appear, and higher up, layers of easterlies and westerlies alternate. Wind speeds at these higher levels are fairly constant (Figure 5-14).

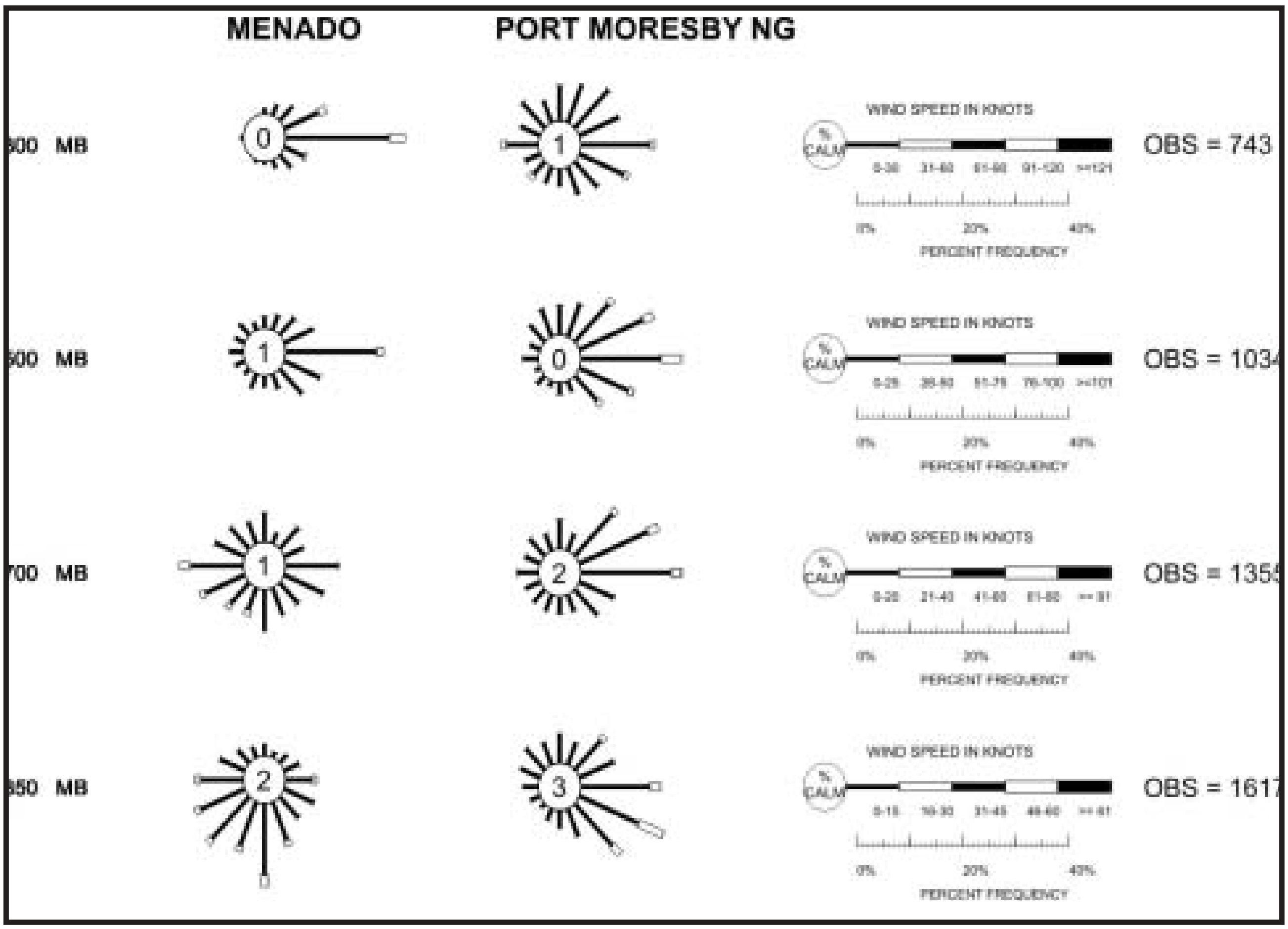

Figure 5-14. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at the chosen locations.

Precipitation. Although the southwest monsoon is the dry season in this area, it is only relatively drier. In the Celebes, August and September are the driest months. Even so, stations in the central mountains receive 8 inches (200 mm) or more of rain during some months in the season (Figure5-15). In the Moluccas, August-October generally have the least precipitation. In New Guinea, the dry period is usually from June-November. The south coast of Papua (and other stations in Papua exposed the monsoon flow) is wettest during the southwest monsoon.

The number of rain days decreases at many locations during the southwest monsoon. Saumlaki on Tanimbar and Hasanuddin on the southwest coast of Celebes receive rain only 8 and 4 days respectively in July. During the transition month of May, Saumlaki experiences rain on 13 days and Hasanuddin 8 days. At Ambon, fully exposed to the monsoon winds, it usually rains on 20 or more days in May-August. The transition to the northeast monsoon begins in late October, and rain days at Ambon decrease to 13 days.

The moist air of the southwest monsoon is much shallower, drier, and more stable than that of the northeast monsoon. The number of thunderstorm days is considerably less. Port Moresby generally experiences only 1 thunderstorm day in May and reports no others during the season. It rains only 4-6 days each month of the southwest monsoon. It rains frequently at Ambon, but thunderstorms are rare. The air stream has picked up moisture, but it still is moist and unstable only up to 8,000 to 10,000 feet. Most months have only 1 thunderstorm day. See Figure 5-16.

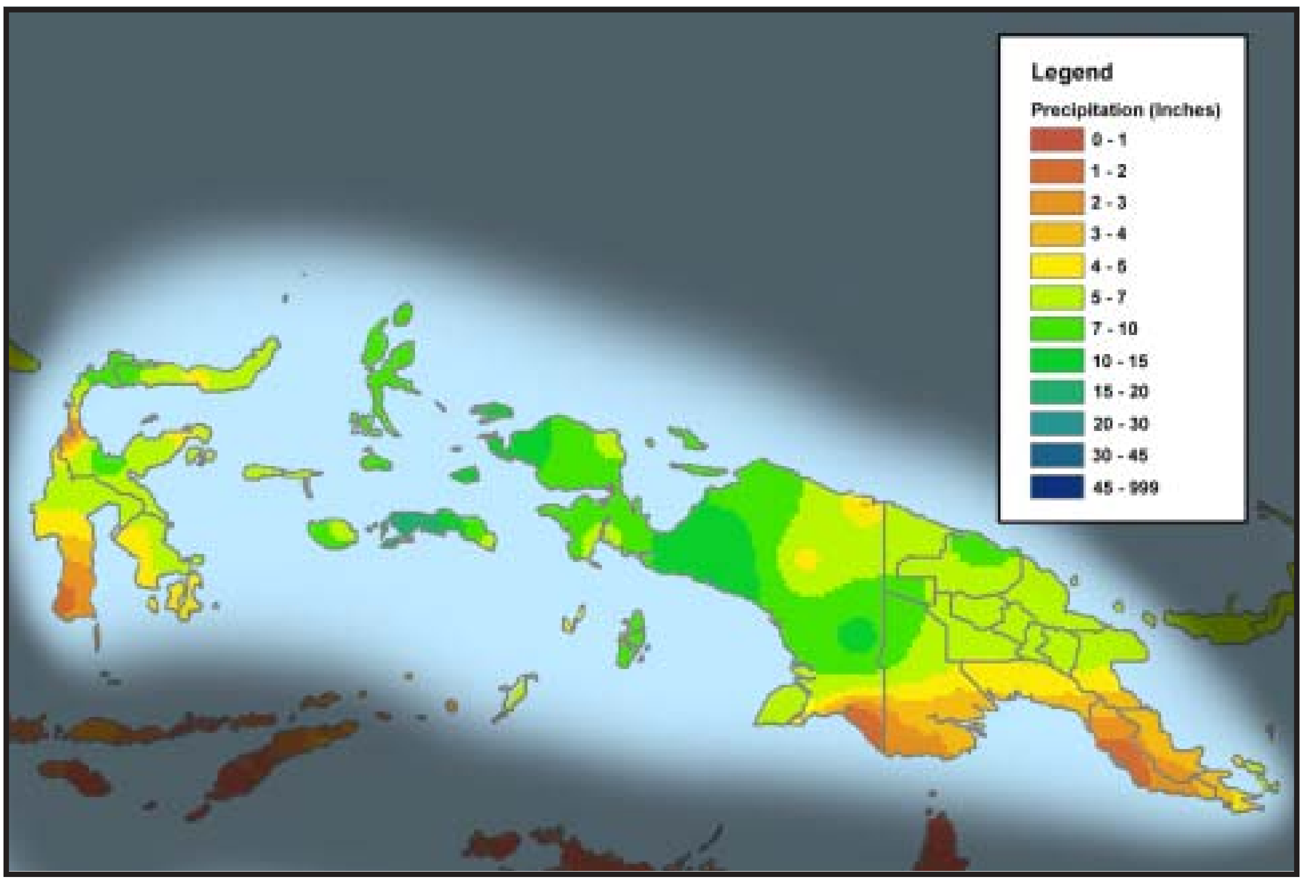

Figure 5-15. July Mean Precipitation. The figure shows mean precipitation in the region.

Southwest Monsoon: May-October

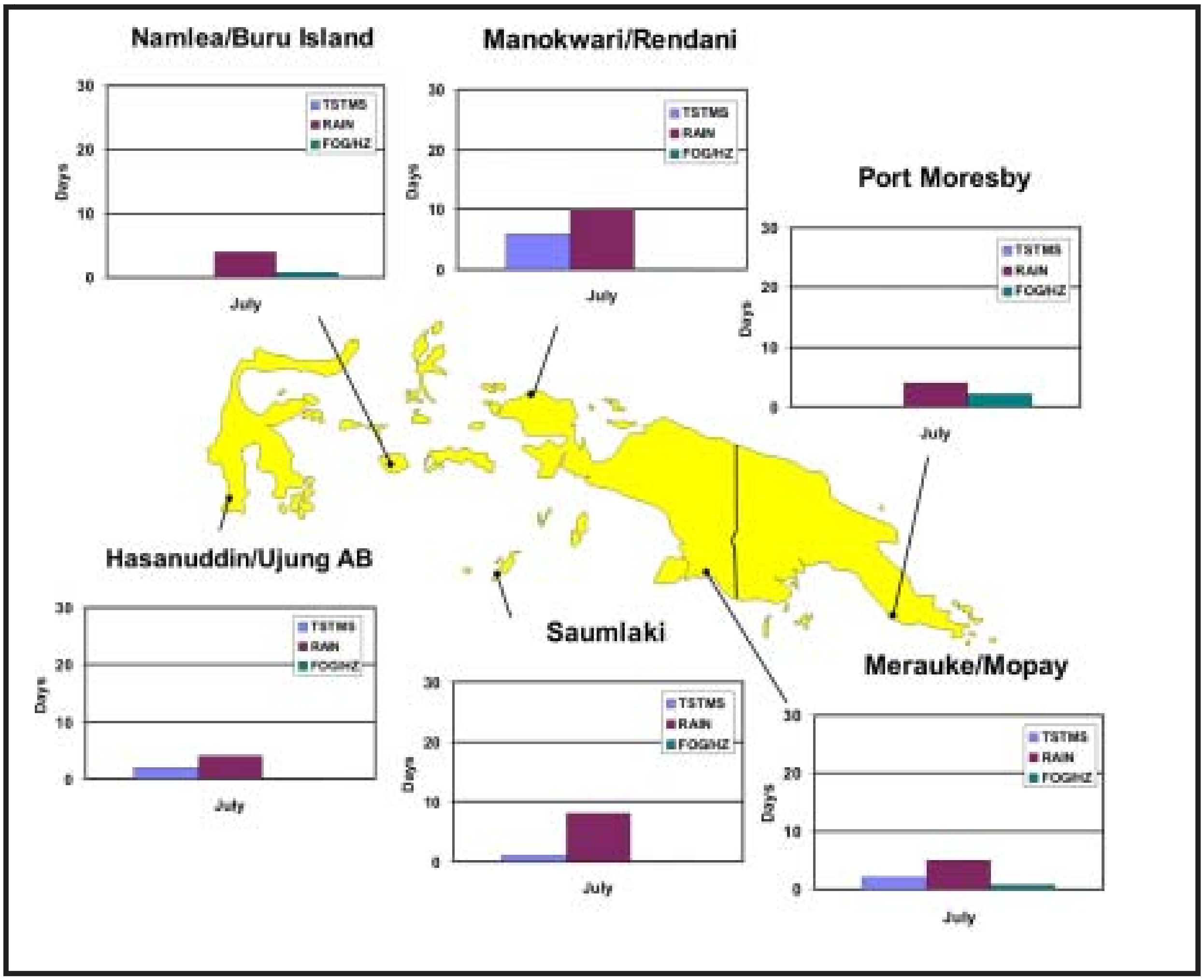

Figure 5-16. Southwest Monsoon Precipitation and Thunderstorm Days, from May to October. The graphs show the average seasonal occurrences of rain, thunderstorm, and snow days for representative locations in the region.

Temperatures. Southwest monsoon temperatures are like those of the northeast monsoon. The southwest monsoon airflow, originating in the belt of high pressure south of the equator, is drier, more stable and perhaps 2-3 Fahrenheit (1-2 Celsius) degrees cooler than the air of the northeast monsoon. Locations exposed to the southwest monsoon have cooler temperatures than lee stations. The mean high range at sheltered stations is 86° to 90°F (30 ° to 32° C). Mean highs at other locations range from 82° to 896°F (28° to 30° C). Mean lows are 73° to 81°F (23° to 27° C). At Sattelburg Mission, the mean high is 68° F (20° C) and the mean low is 63° F (17° C). At Wamena, the mean high in July is 72° F (22° C), and the mean low is 66° F (19° C). See Figures 5-17 and 5-18.

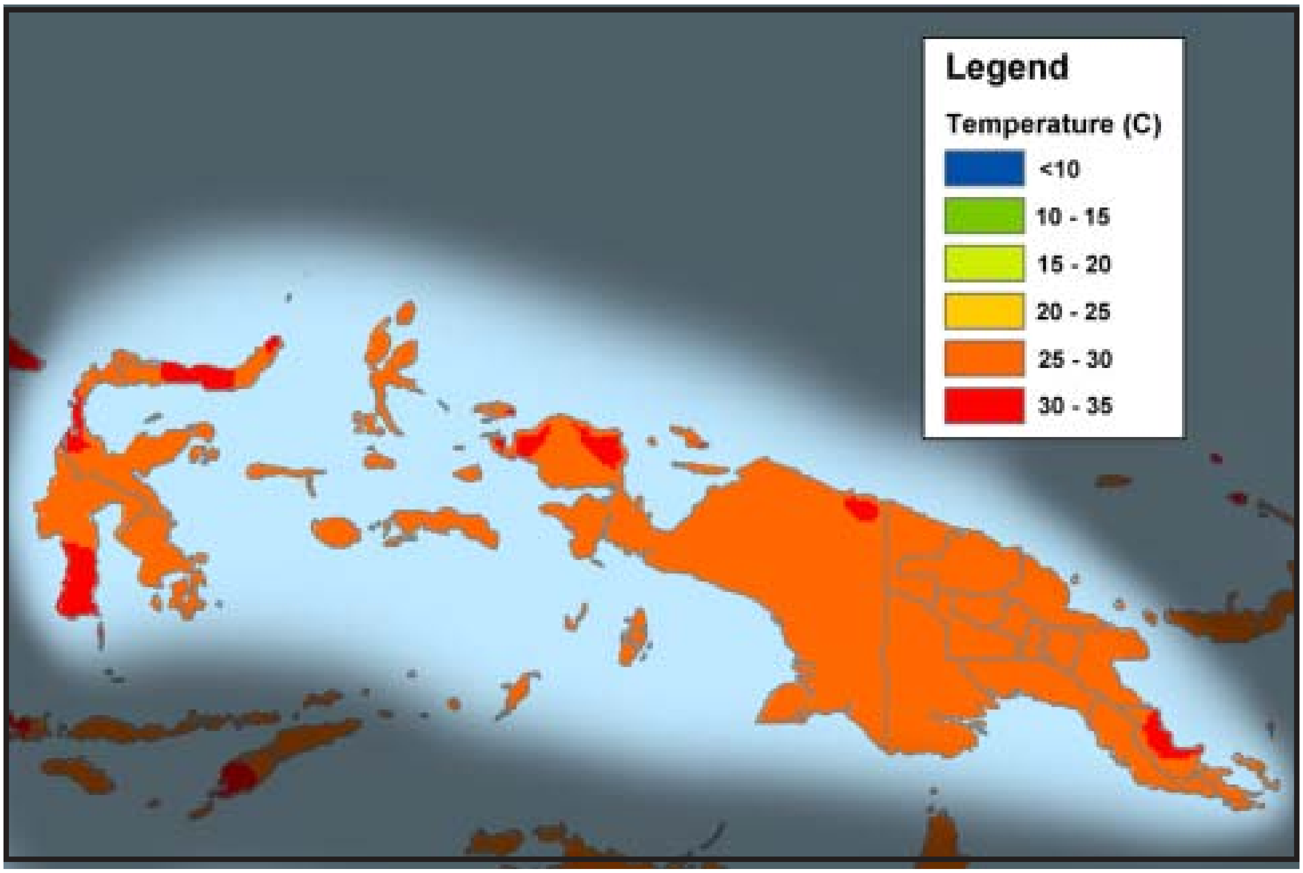

Figure 5-17. July Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the month. Daily high temperatures are often higher than the mean. Mean maximum temperatures during other months may be lower.

Southwest Monsoon: May-October

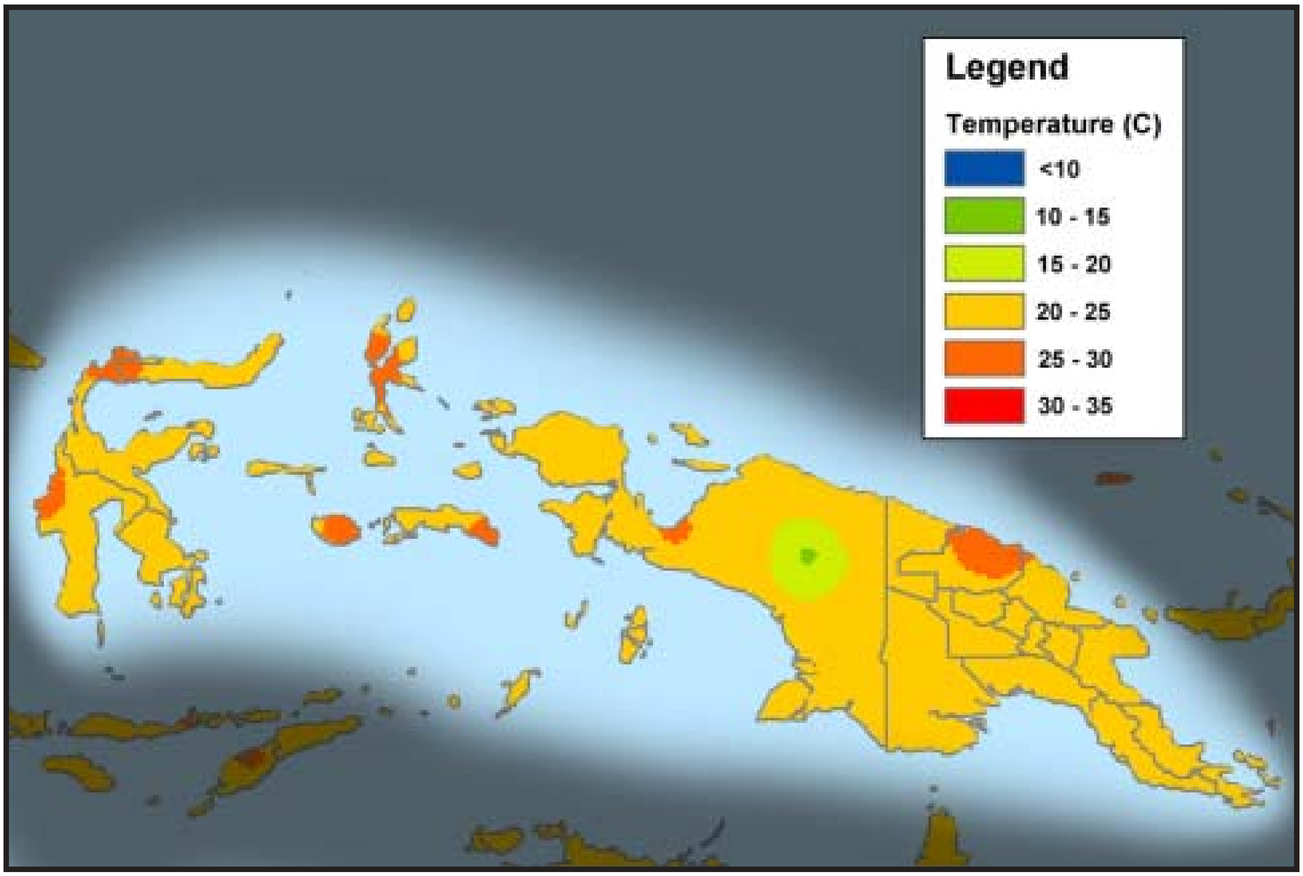

Figure 5-18. July Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the month. Daily low temperatures are often lower than the mean. Mean minimum temperatures during other months may be higher.

Hazards. Rainfall is less during the southwest monsoon, but vast amounts of rain fall in short periods of time at many location in the area. Many rivers frequently overflow their banks, flood entire valleys and spread over vast areas of lowland areas. Roads wash out completely or become impassable because of deep water. Tropical thunderstorms are less frequent during this season but develop to 50,000 feet or more. In addition to heavy downpours, the storms create strong downrush gusts on the surface and violent up and down drafts within the clouds. Severe turbulence occurs in, near, and under the storm clouds. Lightning from the storms is frequent and can be deadly. Strong surface heating will create updrafts and thermal turbulence in the area. The turbulence may reach the moderate category. Winds blowing across mountain ridges will produce moderate to severe mountain wave turbulence over the ridges and up to 50 miles (80 km) downwind. The freezing level is 15,000 feet in this area. From the surface to this altitude, icing is not a threat. Between 15,000 and 25,000 feet, icing becomes a more serious threat. Clouds between these levels will produce clear and/or rime icing. The heat and humidity in the area can cause dehydration, heat stroke, and sun stroke.

Trafficability. Heavy rains reduce roads to mud, swamp lowland areas, and destroy structures. These conditions will seriously impact trafficability. Undergrowth in dense rain forest jungles and in forests on mountain slopes can make off-road movement very difficult or impossible.

Chapter 6

PHILIPPINE ARCHIPELAGO

This chapter describes the geography, major climatic controls, special climatic features, and general weather by season for the Philippine Archipelago in the Western Pacific Basin.

Figure 6-1. The Philippine Archipelago. The figure shows the Philippines in relationship to surrounding countries in the western Pacific region.

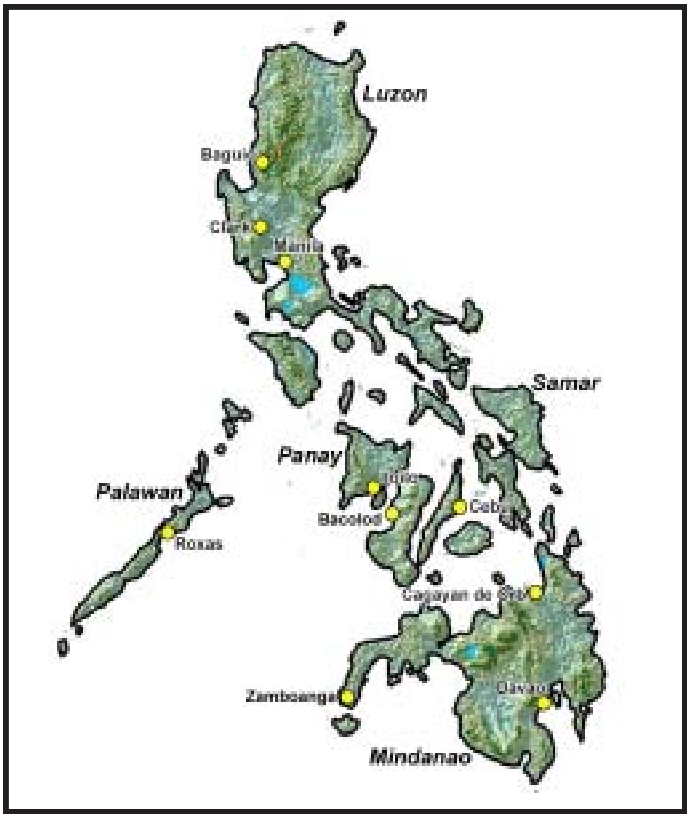

Figure 6-2. Topography of The Philippine Archipelago.

TOPOGRAPHY. The Philippine Archipelago is the northernmost island group of the Malay Archipelago. It extends 1,150 miles (1,850 km) north-south between Borneo and Taiwan (See Figure 6-2). From east to west, the group extends 700 miles (1,127 km). The two largest islands, Luzon and Mindanao, have most of the land. After them, Samar, Negros, Palawan, Panay, Mindoro, Leyte, Cebu, Bohol and Masbate contain most of the remaining populated area. There are 7,100 islands and islets in the archipelago, most minuscule. The archipelago forms a triangle; Mindanao, the Sulu Archipelago, and the islands south of Palawan form the base of the triangle. The Batan Islands, north of Luzon, form the apex of the triangle. The Philippines are 500 miles (805 km) southeast of the coast of Asia. The Sulu Archipelago extends southwest toward Malaysia from Mindanao. The Calamian Group and Palawan Island extend southwest from Mindoro.

The islands of the Philippines are in three groups: the northern, central, and southern. The northern group includes Luzon, the Babuyan Islands, the Batan Islands and many small islands. The central group consists of Mindoro, Palawan, the Visayan Islands, the Romblon Islands, Samar and many small islands. The southern group consists of Mindanao and many small islands as far south as the Jolo group.

Major Terrain Features. The islands are volcanic and each is the top of a partially submerged mountain. The larger islands, such as Luzon and Mindanao, have a diverse topography with mountains near the coasts and broad fertile valleys in the interior. In general, Philippine mountain ranges extend from north to south parallel to the coasts, and often they abut the coasts.

Luzon is the largest island. In the interior, it has broad plains and level, fertile valleys surrounded by mountains. Its coasts are irregular with narrow, interrupted coastal plains. The largest plain and valley on Luzon are the central plain and Cagayan Valley. The central plain of Luzon, 150 miles (240 km) by 50 miles (80 km), is only 100 feet (30 meters) feet above sea level at its center. It extends from the Lingayen Gulf in the north to Laguna de Bay, the largest lake on Luzon, to the south. Cagayan Valley lies north of the Caraballo Mountains between the Cordillera Central (west) and Sierra Madre Mountains (east). This valley, 50 miles (80 km) wide, opens to Babuyan Channel on the north coast.

The mountain ranges on Luzon are generally oriented north to south and parallel the coasts. The largest, the Cordillera Central Mountains, extends from the north end of the central plain to the northern tip of Luzon. Parallel mountain chains that average 5,900 feet (1,800 meters) in height make up the Cordillera Central. Peaks rise to 8,000-9,000 feet (2,500-3,000 meters). The Sierra Madre, the longest mountain chain in the country, extends 215 miles (346 km) along the east coast from northern to central Luzon where it turns southwest and merges with the Cordillera Central to form the Caraballo Mountains. Heights in the Sierra Madre average 3,500 to 5,000 feet (1,100 to 1,500 meters). Few peaks exceed 6,000 feet (1,800 meters). Another narrow range, the Ilocos (or Malayan) range is close to the northwestern coast and rises to 3,500-5,000 feet (1,100-1,500 meters). The Zambales Mountains dominate southwestern northern Luzon. They reach from Lingayan Gulf to Manila Bay. Peaks average 2,500-5,000 feet (760-1,500 meters) with the highest at 6,683 feet (2,030 meters).

South of the central plain, Luzon is dominated by hills, isolated volcanoes and mountains. The Sierra Madre Mingan Mountains extend south from Baler Bay on the east coast to Bayabas Bay on the south where the land narrows and the Bicol Peninsula extends southeastward. There is no coastal plain along the Sierra Madre Mingan Mountains and peaks are generally less than 5,000 feet (1,500 meters). The highest peak in the Sierra Madre Mingans is about 15 miles (24 km) southeast of Laguna de Bay at 7,103 feet (2,150 meters).

Mindanao**,** the second largest island in the archipelago, is the largest island in the southern Philippines. It is roughly triangular with many bays and gulfs. The Diuata Mountains border the Philippine Sea (east coast). The fertile valley of the Agusan River lies west of the Diuata Mountains. Southwest Mindanao has a large lowland, the Cotabato Valley of the Mindanao River (Rio Grande de Mindanao). In southern Mindanao, a mountain range extends northwest-southeast between the southern coast and the lower Mindanao River. Apo Volcano, the highest mountain in the Philippines, reaches 9,692 feet (2,954 meters) on the southeastern border of the Mindanao River basin.

Palawan, 5-30 miles (8-48 km) wide and 278 miles (448 km) long, has a mountain range that averages 4,000-5,000 feet (1,200-1,500 meters) high. The highest peak rises to 6,839 feet (2,079 meters). Narrow coastal plains border the island. Northern Palawan has an area of lowlands.

The central Philippines include the Visayan Islands. All islands, except Samar and Bohol, have a single, longitudinal mountain range with occasional spurs. Panay and Negros have several peaks that reach 6,000 feet (1,800 meters) or more. On Negros, Canlaon Volcano, is 8,087 feet (2,458 meters) high.

Major Water Bodies. The Philippine Sea bounds the area on the east and the South China Sea bounds it on the west and north. The Celebes Sea is to the south. Bashi Channel separates the Philippines from Taiwan. The Sulu Sea borders the Philippines on the west between the Sulu Archipelago and Palawan Island and the Calamian Group. The Sibuyan Sea, the San Bernardino Strait and Verde Island Passage separate the northern Philippines from the central Philippines. The Mindanao Sea and the Sulu Sea separate the central Philippines from the southern Philippines.

Lakes.

*Luzon***.** Lakes include Laguna de Bay in the north, Lake Taal, fed by the Magat River, and Lakes Bato and Buhi in the south. A small lake lies about 7 miles (11 km) southeast of Carranglan in the Caraballo Mountains.

*Mindanao***.** Mindanao has several lakes including Lake Lano, Lake Mainit and Lake Buluan.

Rivers and Drainage Systems.

*Luzon***.** The Cagayan, or Rio Grande de Cagayan, rises in the mountains about 35 miles (56 km) south-southeast of Bayombong. It flows 220 miles (355 km) north to the Babuyan Channel. The Magat and Chico rivers are tributaries of the Cagayan. The Magat rises in the Caraballo Mountains and flows 90 miles (145 km) northeast until it joins the Cagayan. The Chico River in northeast Luzon is a western tributary of the Cagayan River. It flows 140 miles (225 km) from its origin in the Cordillera Central Mountains to its juncture with the Cagayan.

The Pampanga, or Rio Grande de Pampanga, rises in central Luzon. It flows southwest and passes through a marsh before emptying into Manila Bay 25 miles (40 km) northwest of Manila. The Pampanga Chico River in central Luzon is the main tributary of the Pampanga River. Abra River rises in northwestern Luzon in the Cordillera Central. It flows to the South China Sea. Agno River, in northwest Luzon, rises in the mountains and flows to Lingayen Gulf, roughly 125 miles (200 km). Bicol River in southeast Luzon flows 75 miles (120 km) northwest from Lake Bato into San Miguel Bay. Pasig River flows from Laguna de Bay (lake) to Manila Bay through Manila.

Mindanao. The Mindanao River starts in southern Mindanao and winds 200 miles (323 km) to Illana Bay. It forms a wide, fertile basin. Agusan River rises in the highlands of northeast Mindanao and flows northward about 240 miles (388 km) to a bay on the Mindanao Sea.

MAJOR CLIMATIC CONTROLS

North Pacific High. This subtropical high is farthest north and west during July and August when the Asiatic low is also strongest. The resultant pressure gradient helps drive the southwest monsoon. When the North Pacific high is farther north and west than normal, a stronger pressure gradient and an active monsoon season occurs. Conversely, when the high is farther south and east than normal, an inactive season occurs. Located near 30° N, 130°W, the high alternates between a shallow and a deep flow pattern (each phase about 10 days long) called the low frequency oscillation. This causes fluctuations in the northeast monsoon flow over the area.

South Pacific High. The position and strength of this high affects the strength of the South Pacific trade winds, tropical cyclone development and the position of the near equatorial trade wind convergence (NETWC). Variations in its strength cause easterly ripples in the NETWC.

South Indian Ocean (Mascarene) High. Cross-equatorial flow from this high is one of the driving forces for the southwest monsoon. The southeasterly flow curves and becomes southwesterly as it crosses the equator due to the Coriolis force in the northern hemisphere. This flow amplifies the cross-equatorial flow from the Australian high to push the NETWC northward across the Philippines from May through June.

Aleutian Low. This low is strongest in January and centered over the Aleutian Islands in the North Pacific. During Northern Hemisphere summer, it weakens and moves north as the North Pacific high moves north. Although a long way from the Philippines, it affects the northeast monsoon flow there. Since it is strongest at the same time the Asiatic high is strongest, the strong pressure gradient between these two pressure centers causes strong northeasterly flow (mainly over the northern Philippines). Mid-latitude fronts only affect the northern Philippines during the northeast monsoon.

Asiatic High. This cold, shallow continental pressure feature dominates most of the Asian continent during winter. Its circulation, coupled with the circulation of the Aleutian low, drives the northeast monsoon flow over the Philippines. A thermal high, the Asiatic high reaches its maximum strength in December or January. The Asiatic high is the main driving force that pushes the NETWC southward over the Philippines during September through November. Periodic fluctuations in the high cause the NETWC to oscillate north and south. The Asiatic high disappears completely by May or June when it is replaced by the Asiatic low. Although cold, dry air is associated with the Asiatic high, the northeasterly flow over the Philippines has been significantly modified due to its trajectory over water. The trajectory over warm water causes a significant increase in both temperature and humidity.

Asiatic Low. This thermal low exists from May through October and reaches its maximum strength in July. The pressure gradient between the Asiatic low and the North Pacific high is one of the driving forces of the southwesterly monsoon flow. The Asiatic low anchors the western end of the NETWC.

Australian High. This thermal high is present only during Southern Hemisphere winter and reaches its peak strength in July. It is not as strong or persistent as the Asiatic high, but its cross-equatorial outflow is one of the features of the southwest monsoon. The southeasterly winds from this high combine with the southeasterly trade winds from the South Pacific high and the cross-equatorial outflow from the South Indian Ocean high to control the position of the NETWC during the southwest monsoon.

Australian Low. This thermal low forms over Australia during Southern Hemisphere summer. It is strongest during January and helps draw the NETWC southward.

Ocean Currents/Sea Surface Conditions. The warm, North Equatorial Current plays a major role in the maritime climate of the Philippines. Figures 2-3a and 2-3b show the currents in February and August. During Northern Hemisphere winter, the North Equatorial Current bathes the east coast of the Philippines then splits and flows north and south along the coasts. The north current traverses the northern tip of Luzon and becomes the Northeast Equatorial Current. Part of it also flows northeastward as the Kuroshio Current. The Kuroshio Counter Current, influenced by the northeasterly flow, draws cold water southward along the coast of China. The temperature gradient between the Kuroshio Counter Current and the Northeast Equatorial Current makes the South China Sea a favored cyclogenesis zone.

The south current along the east coast divides; part flows south of Mindanao and part recurves eastward as the Equatorial Counter Current. The west coast of the Philippines is washed by a counter current in the South China Sea that moves northward along the coast. Average January sea-surface temperatures vary from about 75°F (24°C) in the north near the Batan Islands to 82°F (28°C) south of Mindanao. During summer, the east coast continues to be bathed by the North Equatorial Current, but it continues northeastward from northern Luzon as the Kuroshio Current. A warm, southwesterly current in the South China Sea flows along the west coast driven by southwest monsoon winds. The Philippines are surrounded by sea-surface temperatures that average 82°F to 86°F (28°C to 30°C) in July.

Northeast Monsoon. Sometimes called “northers,” this is a major air stream in the Philippines. It first reaches the northern Philippines in October as a weak northeasterly flow behind the NETWC as it moves south across the Philippines, but the surface winds can be from the north or east as well. As the Asiatic high strengthens over the Asian continent and the Aleutian and Australian lows deepen, the pressure gradient increases and the northeasterly flow increases in intensity. The northeast monsoon reaches maximum strength in January. It begins to weaken in February and March as the Asiatic high and the Australian low begin to weaken and completely disappears in April. The northeasterly flow usually extends no higher than 8,000 feet. Over the northern Philippines, especially northern Luzon, the Babuyan Islands, and the Batan Islands, the temperate zone westerlies overlay the northeast monsoon.

The northeast trades overlay the northeasterly flow over the remainder of the Philippines. The northeast monsoon brings a maritime tropical air mass with an average surface temperature of 77°F (25°C) to the Philippines.

It typically has a moderate subsidence inversion at about 5,000 feet that helps contain most of the moisture below it. This limits vertical cloud development except where topography causes orographic lifting. The weather with the northeast monsoon in the Philippines is predominantly overcast stratocumulus and heavy drizzle, especially along the east coast. Above the inversion, the sky is usually clear where the dry temperate zone westerlies overlay the northeast monsoon. Middle and high clouds usually accompany the North Pacific trade winds where they overlay the northeast monsoon.

Southwest Monsoon. This major air stream first appears in the Philippines as weak southwesterly flow in May (sometimes as early as April), when the NETWC starts northward. The local surface winds vary from the west to south. It reaches peak strength in August and weakens after that. By October, the southwest monsoon has usually left the Philippines, but it can linger into November, or even December. The warm, humid southwesterly flow reaches much higher than the northeast monsoon flow, as high as 33,000 feet. Temperatures near the surface are 78° to 82°F (25° to 27°C), and the relative humidity rarely falls below 70 percent. This air stream is unstable and causes frequent convective precipitation. In most of the Philippines, the southwest monsoon season is the wet season, especially over the western half of the islands, where rugged terrain induces orographic lifting of the moist air mass and causes rainfall on the windward side of the mountains. Tropical cyclones can cause surges in the southwest monsoon or the northward movement of an equatorial anticyclone can cause a monsoon break, but the flow is constant.

North Pacific Trade Winds. These winds from the northeast, east, or southeast bring warm air to the Philippines, average 81°F (27°C). They arrive in the central and southern Philippines in October as the southwest monsoon weakens. In the northern Philippines, the trade winds overlay monsoonal flow along the eastern Philippines. After the northeast monsoon weakens and retreats in February and March, the North Pacific trade winds then dominate the northern Philippines as well. In April and May, the North Pacific trades dominate until the transition to the southwest monsoon begins in June. Below the trade wind inversion, usually near 5,000 feet (1,500 meters), the maritime tropical air is very moist. Above the inversion, it is very dry. The air mass is convectively unstable, but subsidence prevents intense convective activity over the Philippines from March to May. From July through December, the North Pacific high is weak and the subsidence inversion is destroyed by convergence, so convective activity is more intense in the transition between the southwest and northeast monsoons when the trade winds again prevail over the Philippines.

South Pacific Trade Winds. These winds flow over the southern Philippines from May to July and are similar to the North Pacific trades. Warm, moist air is below a weak trade wind inversion at 5,000-6,500 feet; drier air is above the inversion. These trade winds are very weak and extend only to 8,000 feet. They are almost indistinguishable from the southwest monsoon winds and often are mistaken for the onset of the southwest monsoon in April or May before the NETWC has started north. The trade winds can be distinguished from the southwest monsoon by the weak trade wind inversion that causes less cloudiness above the inversion. The southwest monsoon has no distinguishable low-level inversion and its associated clouds generally extend much higher.

Temperate Zone Westerlies. These winds mainly affect northern Luzon, where they overlay the northeast monsoon, and deliver warm air aloft. They first appear in October over the Batan Islands above 16,500 feet and increase in strength over time. They extend southward over most of the northern Philippines during the northeast monsoon through April. Then, the strengthening southwest monsoon pushes the temperate westerlies northward. The STJ usually stays north of the Philippines over China and Japan, so wind speeds over the northern Philippines are light to moderate. From July through September, there is no trace of the temperate zone westerlies over the Philippines.

El Niño-Southern Oscillation (ENSO). When the El Niño-elevated sea-surface temperatures appear in the eastern Pacific, the western Pacific is 5-6 degrees Fahrenheit (2-3 degrees Celsius) cooler than normal.

This shifts the North Pacific high south and makes it stronger than normal during the southwest monsoon. The TEJ and the Somali jet, both important in the southwest monsoon, usually weaken or disappear. This cuts short the southwest monsoon and limits precipitation. Fewer thunderstorms than normal occur over the western Pacific Ocean. Fewer typhoons occur, especially between July and November. As a result, abnormally dry conditions occur throughout the year when an El Niño is in progress, but thanks to the Pacific Ocean, local rains is not be seriously short although a reduction in storms will be noticeable. In the northern Philippines, precipitation is nearly normal. During the northeast monsoon, temperatures may be warmer than normal during an El Niño because much of the cold air is held north with the polar front. Cold surges are fewer, but those that do come through are very strong. In addition, the trades usually weaken and shift northward a few degrees of latitude. As the ENSO decays, the North Pacific high shifts northward and normal convective activity returns to the Philippines.

La Niña. The La Niña phase typically follows the El Niño and is its opposite. Warmer water temperatures near the Philippines cause the North Pacific high to shift farther north than normal. This allows more tropical cyclones to form and causes more precipitation in the Philippines. More flooding and mud slides occur than in a normal year.

SPECIAL CLIMATIC FEATURES

Cold Surges. These intrusions of cold, dry air move southeastward from the Asian continent at 4-20 day intervals. They are most frequent in winter when the Asiatic high is strongest (November-January). A strong cold front develops ahead of the cold surge and pushes southward. Sharp temperature drops accompany the front. When a cold surge reaches the South China Sea, it can generate considerable convective activity early in winter when the ocean temperatures are still warm. Also, the surge enhances the northeast trade winds for about 3-4 days and, in turn, enhances convection over the western Pacific Ocean. Northern Luzon, the Babuyan Islands and the Batan Islands can experience northeast winds as high as 40 knots. During December and January, 4 cold surges per month reach the equatorial South China Sea. By the time they reach the northern Philippines, the cold, dry air mass has been modified by its travel over the warm ocean; the air has been warmed and its moisture content has increased. Occasionally, a strong cold surge can reach as far south as Mindanao, but the air has been so modified, there is little difference between the cold surge air mass and the northeast trades of the central and southern Philippines during winter.

Equatorial Anticyclones. These occur a mean of 8 times per year, mostly between June and September, and last for 4-9 days (sometimes as long as 16 days). They are strongest when the Australian high is strongest. They develop as buffer cells south of 10° N in the equatorial region and drift north to become equatorial anticyclones. They can cause monsoon breaks in the southwest monsoon because they establish an anticyclonic flow pattern in the lower levels over the region. They may also affect the path of typhoons. Strong, north-moving anticyclones over the western Pacific Ocean or the South China Sea can cause west-moving typhoons to alter their course and move eastward or northward. In the case of the Philippines, typhoons curve and miss the Philippines. While the Philippines may be spared a direct hit, they may still get heavy rainfall and strong winds if the typhoon comes close.

Subtropical Cyclones. These mid-tropospheric disturbances usually occur north of 10-15° N and south of 35° N from May through September at a rate of 3 per year. Two-thirds occur in July and August. The life-cycle averages 5 days, but can be 2-11 days. Subtropical cyclones have a cold core at low levels and a warm core aloft. A surface low may not develop. The subtropical cyclones mainly affect the ocean areas, but the strongest winds and the heaviest rain bands form a couple of hundred miles (several hundred kilometers) from the cyclone center and can affect land areas. The northern Philippines is normally the only part of the region affected by subtropical cyclones.

Tropical Cyclones. These storms pose a major threat to the Philippines, especially north and central areas.

Their high winds, heavy rainfall, and storm surges cause widespread flooding, enormous property damage and loss of life every year in the Philippines. They occur in every month, but most occur from May to December, with the peak rate in August. The western North Pacific Ocean is the most active tropical cyclone area in the world. It averages 31 tropical cyclones per year; 4 of these are tropical depressions, nine are tropical storms, and 18 are typhoons. The Philippines are hit by 7 or 8 tropical cyclones per year. The average is 4-9 per year, but as many as 12 and as few as 3 have occurred. They cause most of the rainfall between May and December. Luzon gets the most of tropical cyclones in the Philippines. Of the tropical cyclones that strike the Philippines, 61 percent hit Luzon (4-5 per year). The central Philippines get 34 percent or 2-3 per year. The southern area is least likely to be hit by a tropical cyclone as only 6 percent hit here (about 1 every 2 years).

Most tropical cyclones that strike in the Philippines form in the North Pacific Ocean. The farther from the Philippines they form, the more time they have to develop into typhoons (winds 64 knots or higher) or super typhoons (winds 130 knots or more). Those that form close to the Philippines are more likely to be tropical depressions (winds less than 34 knots) or tropical storms (winds 34 knots to less than 64 knots) at landfall. See Figure 2-44 for the favored areas of tropical cyclone formation and their usual tracks over the Philippines for each month.

Near Equatorial Trade Wind Convergence (NETWC). This boundary between Northern Hemisphere and Southern Hemisphere air masses affects the Philippines from May to mid to late July as it moves to its northernmost position across Taiwan in August. It recrosses the Philippines in September and October as it moves to its southernmost position south of Indonesia in December through March. From November through April, the NETWC is south of the region. The NETWC reaches its southernmost position in January or February when the northeast monsoon is strongest.

Movement of the NETWC north or south is often quite erratic. Rapid surges north or south, caused by changes in the relative strengths of the air flow on both sides of the NETWC, can cause wide make variations from the mean position. Cyclones can form along the northern edge of the NETWC, and their movement along the NETWC also causes large deviations from the mean position of the NETWC. Weather conditions along the NETWC are usually cloudy with generally convective precipitation. Strong surface winds are usually associated with mesoscale systems that tend to move along the NETWC. There is very little temperature discontinuity across the zone.

Polar Front. Most of the region is too far south to be affected by mid-latitude fronts. Fronts reach the Philippines only during the northeast monsoon. In January, the polar front is north of most of the Philippines except for the Batan Islands, the Babuyan Islands, and northern Luzon. Strong, cold surges can push it further south over Luzon. The front quickly undergoes frontolysis as it interacts with the northeast trade winds and the air masses across the front become homogenous. This makes the frontal boundary difficult to trace at the surface. Polar fronts trigger cloudiness and rainfall along the east coast of Luzon where orographic lifting increases the cloudiness and rainfall. Sometimes, middle and western sections of the island are also affected by clouds and rainfall. On occasion, an especially strong cold surge can push the polar front as far south as Mindanao, but its effects are hardly noticeable because the air behind the front has been so modified. During summer, the polar front stays north of the Philippines.

Tropical Easterly Waves. These disturbances in the easterly flow south of the subtropical ridge can bring extensive cloudiness and rainfall to the region (sometimes heavy rain showers or continuous rain) for 2-3 days, especially on the east coasts. Easterly waves rarely affect the region in the northeast monsoon, but they can affect the islands as often as twice per week during other seasons, especially the southwest monsoon.

Cloud Clusters. Clusters occur during summer and form as the result of convergence of the low-level winds and moisture fields and orographic lifting. They are convective cloud masses consisting of multiple cumulonimbus clouds capped by cirrus shields with widespread stratiform cloud decks. Cloud clusters generate heavy rainfall and cause flash flooding. They can last from hours to a couple of days.

Foehn. These are strong, warm, dry, katabatic winds that descend leeward slopes of mountains. While not common in the Philippines, foehns do occur and are most likely on the lee side of the largest mountain ranges, especially on Luzon and Mindanao.

Land/Sea Breeze. All coasts of the Philippines experience land/sea breezes, especially the larger islands. They occur all year, but the southwest monsoon season is when the land/sea breeze is strongest; it reaches as far as 19 miles (30 km) inland. They are most noticeable when the synoptic weather pattern is weak or during breaks in the monsoon flow because the monsoon flow or other synoptic scale systems can mask them.

Mountain Waves. These occur downwind of the north-south oriented mountains. Severe-to-extreme aircraft turbulence is possible downwind from the ridgeline to a distance equal to fifty times the ridge height.

NORTHEAST MONSOON.

General Weather. In the Philippines, the winds during the northeast monsoon are generally from the northeast, but vary widely locally. The North Pacific trades vary from northeast to southeast. Rainfall is heaviest in the east, especially along the east coast and on the windward side of the mountains, during the northeast monsoon. The transition periods are included in the two monsoon seasons, so the weather during the transitions at the beginning and end of the season varies slightly from the weather at the height of the season. These inter-monsoon periods are when the trade winds usually dominate the weather and the islands have less cloudiness and rainfall than at the height of the season.

The northeast monsoon is mainly driven by the Asiatic high and the Aleutian low. Both systems reach peak strength in December and January. The air mass dominating the northern Philippines originates in the Asiatic high but is modified by passage over water before it reaches the Philippines. Polar surges from the Asiatic high are also modified by the time they reach the Philippines, but they do cause lower temperatures and increased cloudiness and precipitation. Surges sometimes occur in series of 2-3, especially in December. After a series of surges, frontogenesis or cyclogenesis sometimes occurs over the Taiwan-Okinawa area. This situation causes the best weather over the Philippines with clear skies at night and few clouds during the day as maritime North Pacific trade wind air is over the islands.

April has the least cloudiness and rainfall of any month of the year in most of the Philippines, but it is not true everywhere thanks to topography. The Asiatic high that controlled the weather during the northeast monsoon season has weakened and almost disappeared. The Asiatic low that replaces it has started to develop but has not yet reached maximum strength. Consequently, North Pacific tradewinds dominate the weather in the Philippines most at the end of the season, especially during April.

The NETWC is south of the Philippines during the northeast monsoon, so the Philippines are subject to the northeasterly flow or “northers” throughout the season. Surface fronts affect the Philippines only during the northeast monsoon. These fronts cause clouds and rainfall along the east coast. Strong fronts can also cause clouds and rain in the middle and western portions of the area. Toward the end of the season, the polar front can still move over Luzon periodically, but the modified polar air behind the front has less cloudiness and precipitation associated with it than earlier in the season. The easterly winds behind these fronts are often mistaken for the trade winds. When a wave forms along the polar front in the vicinity of Taiwan-Okinawa, it usually moves northeastward towards Japan, but the trailing front can oscillate off the northern coast of Luzon and cause cloudiness and intermittent rain there for days. Easterly waves seldom affect the northern Philippines during the northeast monsoon, but they cause extensive cloudiness and rainfall along the east coast for as long as 2-3 days when they do. Weak easterly waves may cause only clouds.

The main typhoon season in the western North Pacific is the southwest monsoon, however, from September through November, the region experiences a period when typhoons are most likely to strike. This period can extend through December. In November and December, typhoons usually cross east to west over Luzon between 12° N and 13° N. The average time over land is 20 hours. Typhoons are rare from January through April. During these months, they usually cross Luzon between 15° N and 16° N. Those north of about 14.5° N are usually only over land for 11 hours. Typhoons from the South China Sea rarely strike the Philippines and are weaker than the storms that originate in the North Pacific Ocean east of the Philippines. Only two storms have struck the Philippines from the west in the last 20 years

Sky Cover. It is cloudy over most of the Philippines during the northeast monsoon, especially along the east coast and on the windward side of the mountain ranges. The western coast of northern Luzon has the least sky cover because the Cordillera Central Mountains, which parallel the coast, protect the coast from the northeast monsoon. In general, clouds decrease toward the west; the east coasts are cloudier than the interior or west coasts because of topography. Mean cloud cover is broken to overcast during the northeast monsoon, except along the west coasts where locations average only scattered to broken. Normally, the northeast monsoon extends to 8,000 feet, and skies are clear above that height in northern Luzon. Farther south, middle and high clouds are present above the monsoon layer. By April, the trade winds dominate the weather over most of the Philippines. The southwest monsoon does not yet influence the weather. As a result, April is one of the least cloudy months of the year.

Ceilings below 3,000 feet are more frequent in the Batan and Babuyan Islands north of Luzon than on Luzon. Ceilings below 3,000 feet occur there up to 40 percent of the time in the afternoon early in the season and, by January, decrease to 28 percent of the time or less. In the northern Philippines, the highest occurrence of ceilings below 3,000 feet is in the windward mountains. The next most frequent area is in the Cagayan Valley. Although protected on the east by the Sierra Madre Mountains, the valley opens to the north. This lets the northeast monsoon transport moisture into the valley, and the mountains, which surround the valley on three sides, trap the moisture. The subsidence inversion usually associated with the northeast monsoon keeps a lid on the moisture and over the valley. Ceilings less than 3,000 feet occur more than 60 percent of the time there in November through January in the morning and more than 50 percent of the time in the afternoon. In April, those ceilings occur 20-30 percent of the time. Along the west coast of northern Luzon where the mountains shield the coasts from the northeast monsoon, ceilings less than 3,000 feet are rare (Figure 6-3). In the Cordillera Mountains, ceilings less than 3,000 feet are more frequent and occur more than 50 percent of the time in the late afternoon. Exposed east coast areas have ceilings below 3,000 feet 25 percent of the time in the afternoon early in the season and 10-15 percent of the time late in the season. Morning frequencies are slightly lower.

Ceilings less than 3,000 feet in the central and southern Philippines follow the same pattern where windward locations have the most clouds and sheltered and lee side locations have the least. Even the locations with the most clouds rarely report ceilings below 3,000 feet more than 20 percent of the time in the afternoon or 10 percent of the time in the morning. Ceilings above 3,000 feet are rare.

Visibility. Visibility is generally good. The worst visibility occurs on the windward slopes of the mountains and hills in clouds and precipitation. The subsidence inversion usually present during the northeast monsoon helps keep the moisture near the ground. Haze is common in the Philippines, especially on the lee sides of the mountains in the interior of the islands and in the mountains, but the visibility is rarely below 3 miles (4,800 meters). Visibility of 3-6 miles (4,800-9,000 meters) in haze is common; many stations report

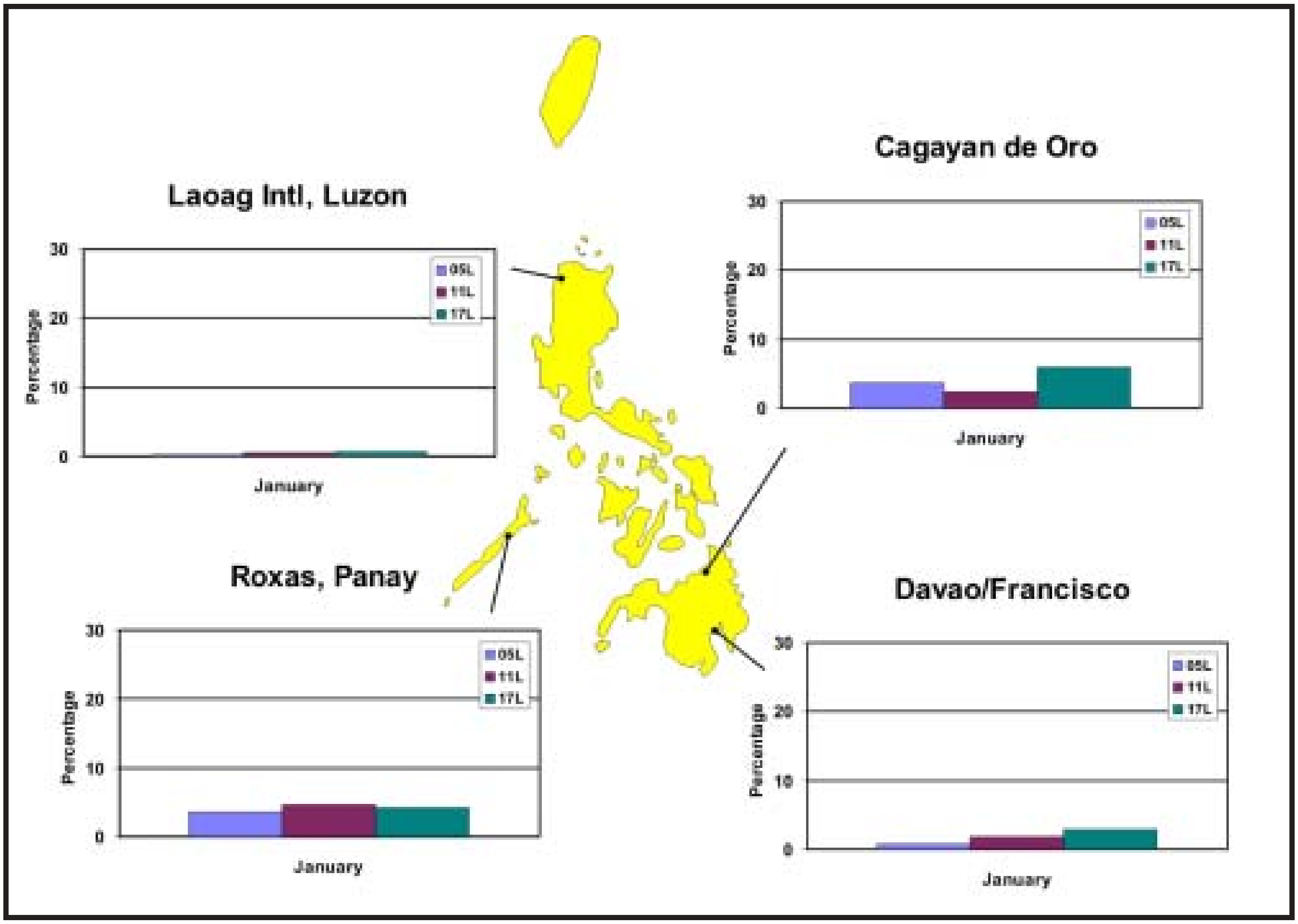

Figure 6-3. Northeast Monsoon Percent Frequency of Ceilings Below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet based on location and diurnal influences.

haze as many as 30 days per month. Fog is not common except in the interior valleys and plains and in the mountains where low clouds shroud the slopes.

On the northwest coast of Luzon, where the cloud cover is at a minimum during the northeast monsoon, haze occurs 10-20 days per month, depending on the location, but fog is rare except in the mountains. The lack of cloud cover allows some radiation cooling at night. It is dry in this area during the northeast monsoon and blowing dust occurs 8 days per month. Neither haze or dust reduces the visibility to less than 4,800 meters. For example, Baguio, in the Cordillera Central Mountains of northwest Luzon, reports haze and fog over 25 days per month, but the visibility there is below 4,800 meters 10 percent of the time or less in the early morning and late afternoon during most months (Figure 6-4). In the central Philippines, haze occurs 5-10 days per month in the east and over 20 days per month in the west. Fog occurs only 1-2 days per month at some locations and visibility less than 4,800 meters occurs rarely. In the southern Philippines, locations near the east coast of Mindanao have haze 10-20 days per month, but fog is rare. Visibility less than 4,800 meters near the east coast, mainly in precipitation, occurs less than 10 percent of the time. Inland, haze occurs nearly every day in the mountains on Mindanao and along the lee side coasts. Fog occurs in the mountains 5 days per month but rarely elsewhere. Blowing dust occurs 1 day per month near the south coast of Mindanao but

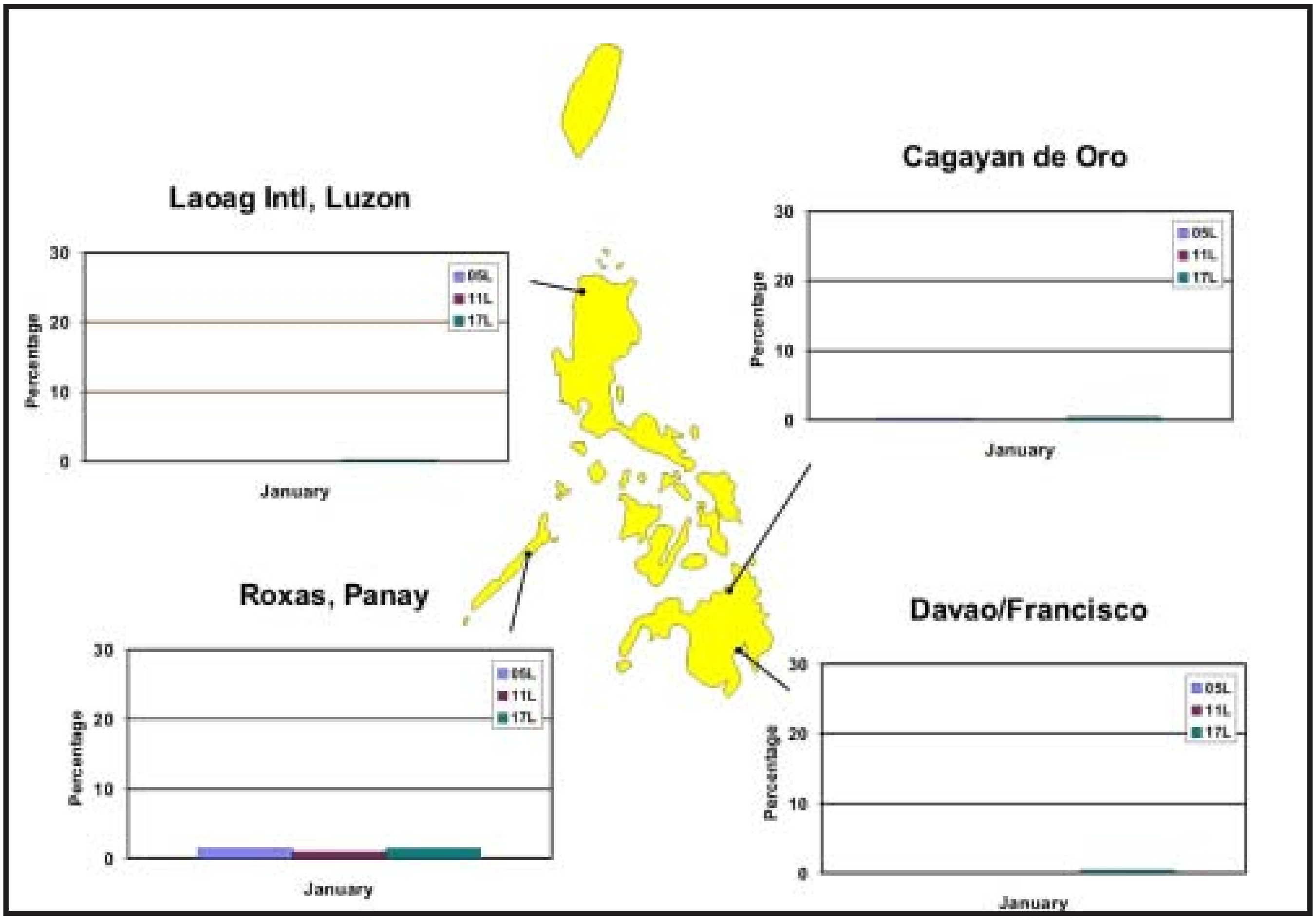

Figure 6-4. Northeast Monsoon Percent Frequency of Visibility Below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percent of visibility below 4,800 meters based on location and diurnal influences.

up to 4 days per month on the Zamboanga Peninsula. Visibility less than 4,800 meters occurs under 5 percent of the time.

Surface Winds. These are extremely variable due to rugged terrain. During the northeast monsoon, the winds are predominantly from the northeast at 6 knots. The wind can be from the north or east because of terrain steering. Land/sea breezes occur mainly in the central and southern Philippines where the northeast monsoon is weak and the North Pacific trade winds dominate. In the northern Philippines, where the northeast monsoon circulation is stronger than anywhere else in the Philippines, the land/sea breeze is not as evident. The northeast monsoon flow enhances sea breezes along the east coast, but overwhelms land breezes. On the western coasts, monsoonal flow damps the sea breeze and makes a land breeze indistinguishable from the monsoon flow.

Although the northeast monsoon usually weakens and disappears by April, the surface winds remain predominantly from the northeast under the North Pacific trade winds. The winds vary from north through southeast with terrain. Average winds over the Philippines in April are northeasterly at 4-6 knots. Calm and light variable winds occur more often because the large scale circulation is weak. Local wind circulations are also more common. The land/sea breeze occurs throughout the Philippine coasts. The sea breeze starts by late morning and peaks in the late afternoon. The land breeze begins once the land cools after sunset. Surface winds above 28 knots are not common in the Philippines; they do occur with tropical cyclones, cold surges, and thunderstorms. Thunderstorms and tropical cyclones are more common in November, December, and April when the northeast monsoon is weakest. See Figure 6-5 for surface wind roses.

In the northern Philippines, the surface winds are predominantly from the northeast to east at speeds up to 17 knots. The exposed east coasts experience the strongest winds, but winds greater than 28 knots are rare. Calms occur in the interior an average of 25-40 percent of the time. Toward the end of the season, calms occur up to 45 percent of the time. In the central Philippines, the lee sides of some islands and the islands farthest west have calms as much as 33 percent of the time. Otherwise, the monsoon flow from the north to northeast predominates. Strong winds are infrequent. In the southern Philippines, the north to northeast winds are mostly under 7 knots but occasionally reach 17 knots. Inland and in the mountains, calms occur 30-50 percent of the time, usually at night.

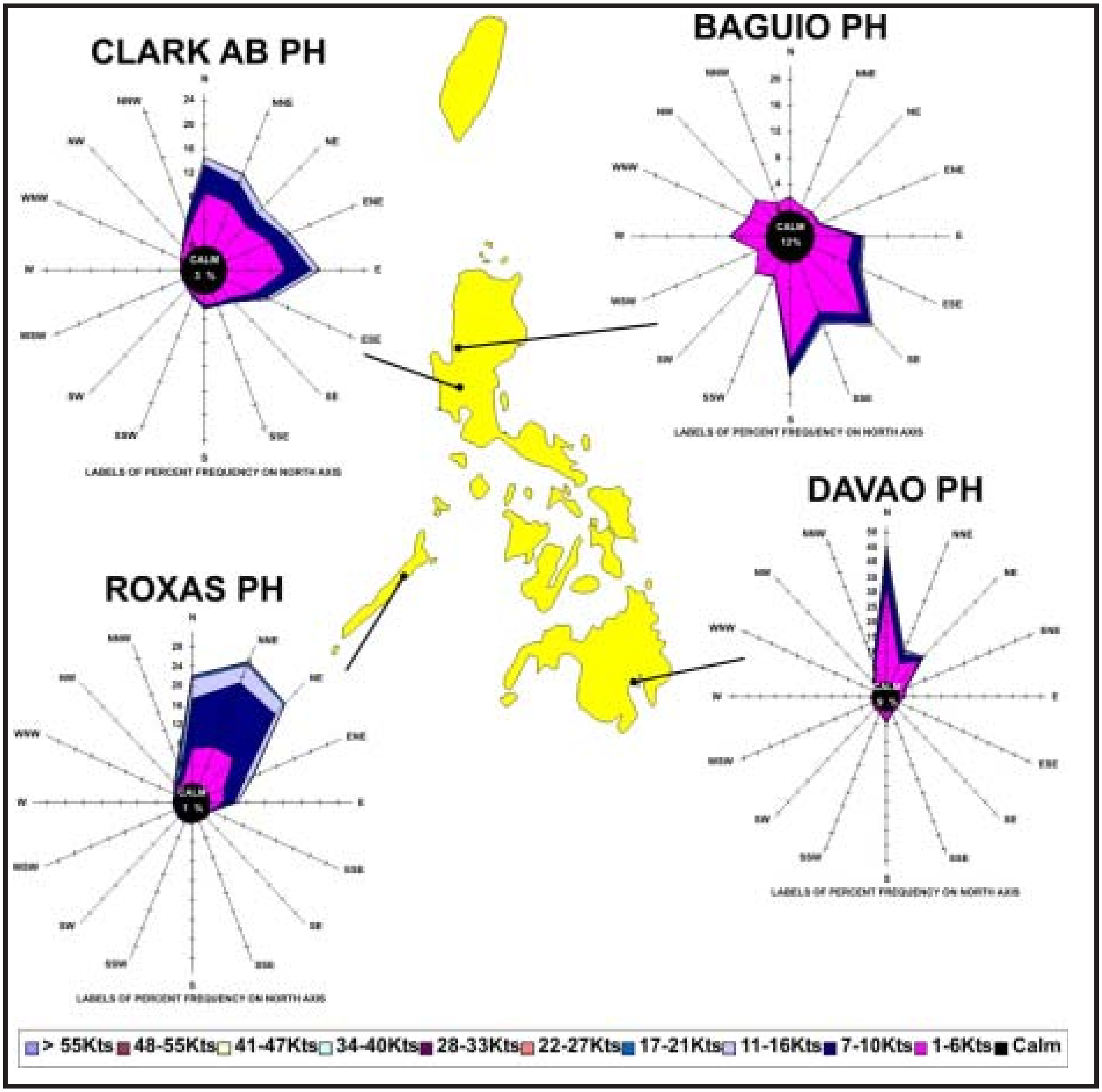

Figure 6-5 January Surface Wind Roses. The figure shows the prevailing wind directions and range of speeds based on frequency and location.

Upper-Air Winds. Temperate zone westerlies dominate above the northeast monsoon over the northern Philippines (see Laoag in Figure 6-6. They appear in October over the Batan Islands above 16,500 feet. As they increase in strength, they extend south to about 13° N, where they remain through April. The January 850-mb winds at Laoag are predominantly from the northeast through southeast at speeds up to 15 knots. Speeds up to 30 knots are possible from the east-northeast through east-southeast. At the 700-mb level and higher, the prevailing wind direction is southwest through west. Speeds at 700 mb are mostly 20 knots or less with speeds up to 40 knots (occasionally 60 knots) possible. The 300-mb level winds are usually 60 knots or less, but speeds of 90 knots are possible. By April, the 850-mb winds become more southerly with prevailing directions of southeast through southwest.

Over the central and southern Philippines, the North Pacific trade winds prevail above the northeast monsoon. The 850-mb winds are from the northeast through east at speeds usually below 30 knots, but speeds up to 45 knots (rarely 60 knots) are possible. At 700 mb, the east-northeast through east-southeast winds average under 20 knots with winds up to 40 knots possible. From the east, winds as high as 60 knots are also possible. At 500 mb, the strongest winds from the southeast occasionally reach 75 knots. The 300-mb winds blow from the east-northeast through south-southeast at speeds of 30-60 knots.

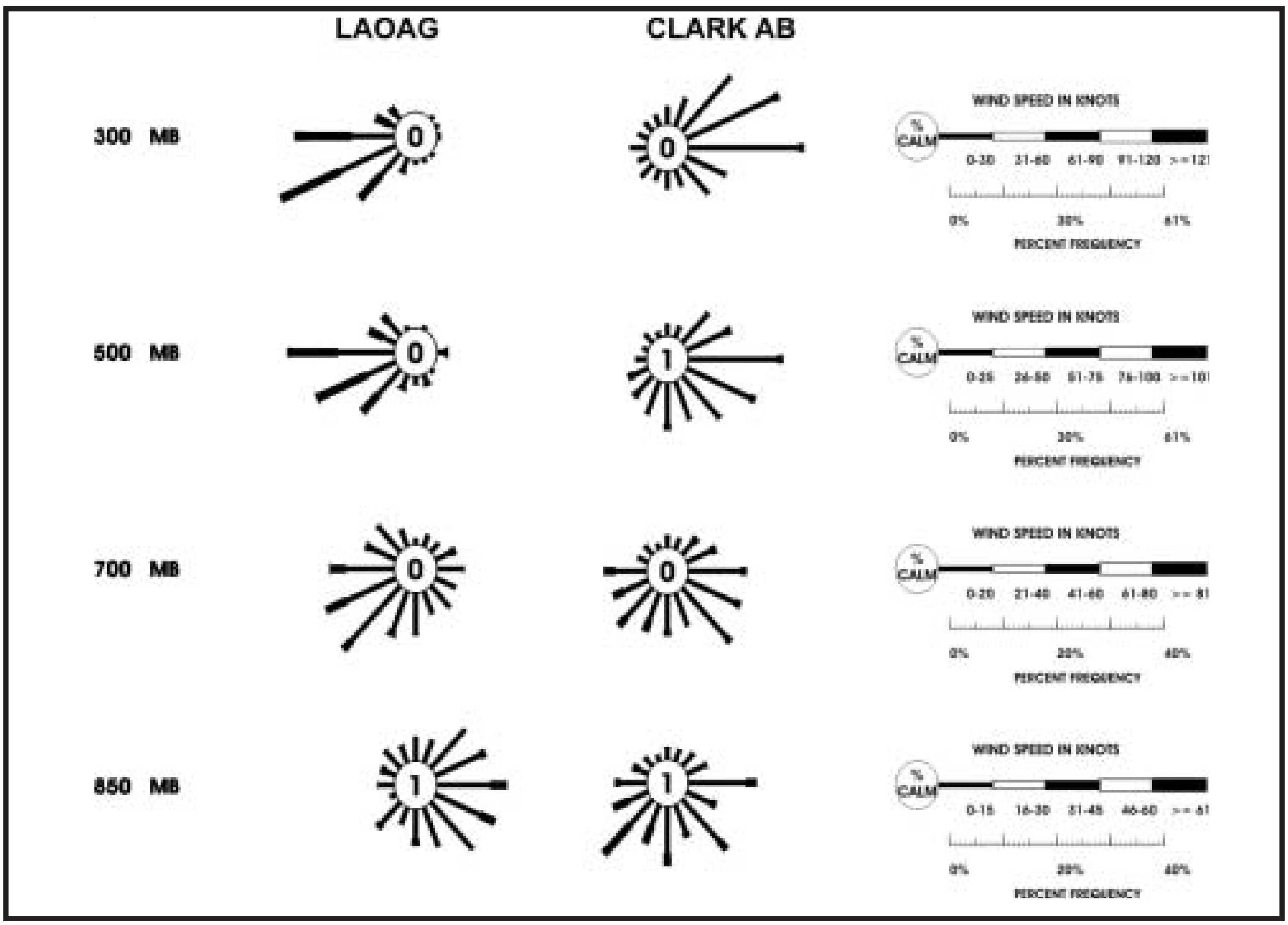

Figure 6-6. January Upper-Air Wind Roses. The wind roses depict the wind speed and direction averaged for all hours for standard pressure surfaces between 850 and 300 mb at Laoag and Mactan International.

Precipitation. Rain falls over the eastern Philippines from stratus associated with cold surges from the Asiatic high and the polar front. The central parts of the islands get light precipitation and the western coasts have only a slight increase in cloudiness and rain. Twenty inches (500 mm) of rain or more per month falls over the eastern part of the islands and less than 2 inches (50 mm) per month falls over western and northern Luzon and the western islands of the central Philippines. Figure 6-7 shows the mean rainfall for January. Averages are higher in November and December when tropical cyclones occur most and the northeast monsoon is weakest.

All Philippine east coasts have rain more than 20 days per month in January (see Figure 6-8). In general, rainfall days decrease from east to west. The west coast of northern Luzon and the westernmost islands of the central Philippines experience rainfall 5 days per month or less. In April, the eastern islands of the central Philippines and eastern Mindanao still experience rain 20 days per month or more, but the rainfall days along the eastern coast of the northern Philippines on Luzon are fewer than during January.

Extreme monthly rain amounts of 35-60 inches (900-1,525 mm) occur on the east coasts of the northern and southern Philippines and the eastern central islands with tropical cyclones early in the northeast monsoon season, usually November or December. The highest 24-hour rainfall along the east coasts also usually occurs in November and December when 16 inches (400 mm) in 24 hours are possible. Maximum 24-hour rains of 10-13 inches (250-330 mm) inland from the east coast of the central and southern Philippines decrease westward to 8 inches (200 mm) in the west.

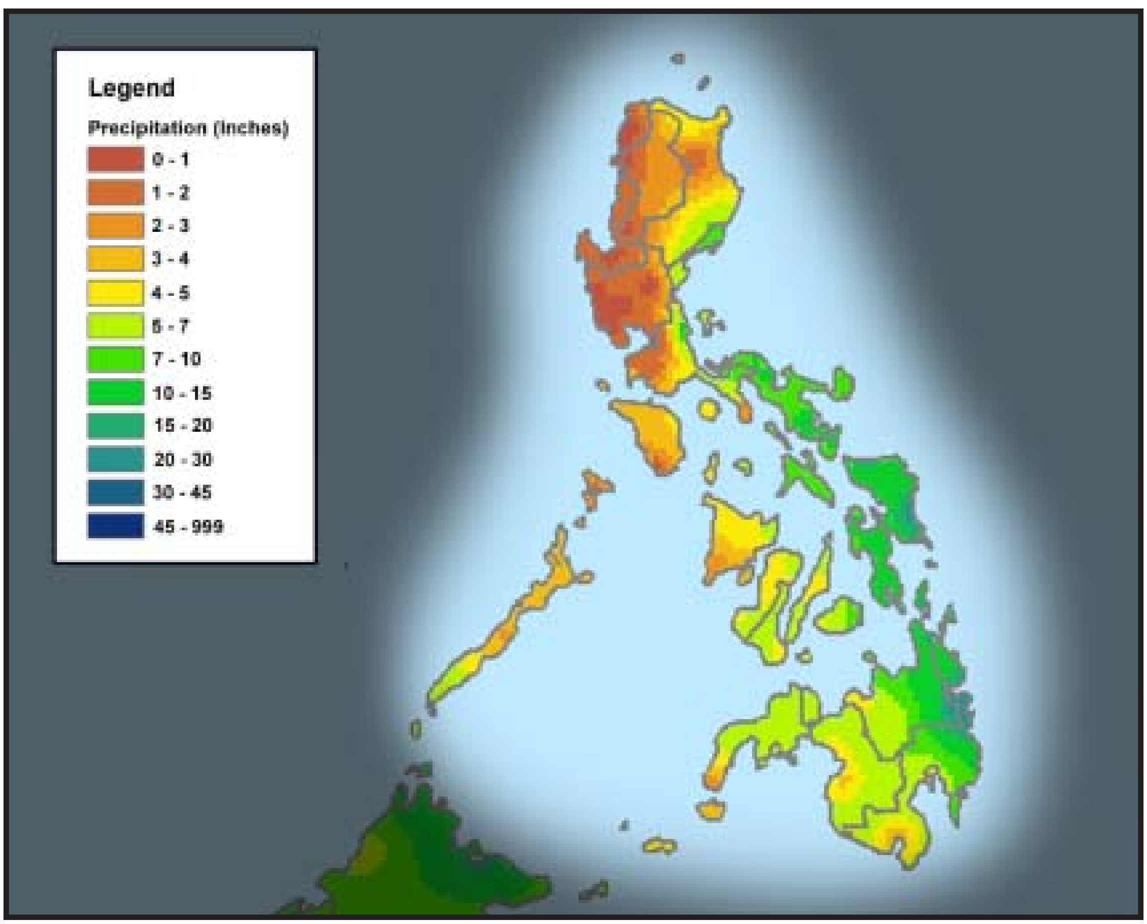

Figure 6-7. January Mean Precipitation. The figure shows mean precipitation for the Philippines in January when the northeast monsoon is at its peak.

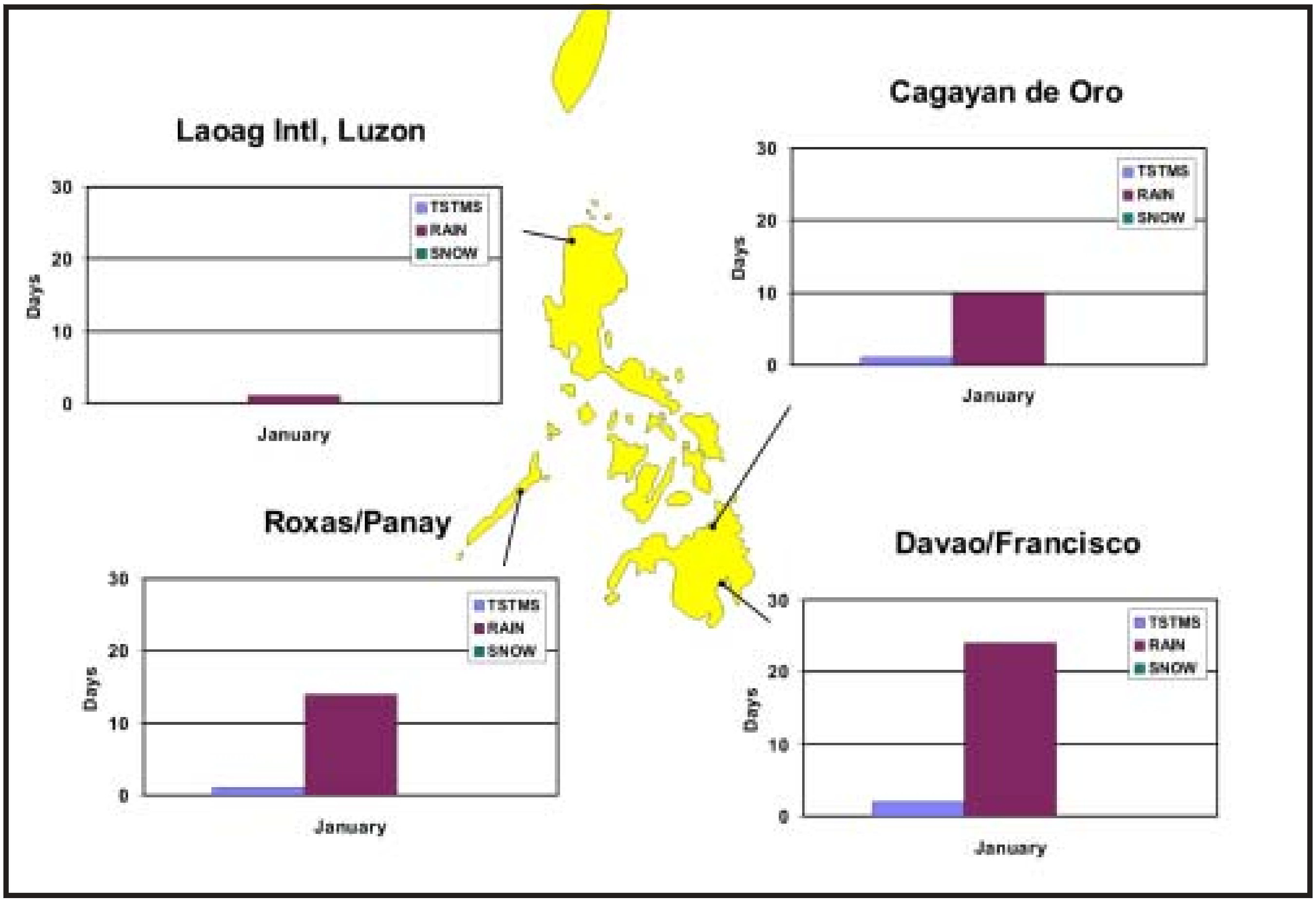

Figure 6-8. Northeast Monsoon Mean Precipitation and Thunderstorm Days. The graphs show the average northeast monsoon occurrences of rain and thunderstorm days.

See Figure 6-8 for typical thunderstorm days during the northeast monsoon season. Thunderstorms are most numerous during November, December, and April. During January, the northern Philippines rarely have thunderstorms and the central and southern Philippines have 1-2 thunderstorm days per month. Southern Mindanao, less affected by the northeast monsoon, experiences up to 6 thunderstorm days in January. By April, southwest Mindanao experiences as many as 14 days with thunderstorms, and the rest of the island has 5-10 days. Northwestern Luzon, the area with the least cloud cover in April, has 5-10 days with thunderstorms, because of the increased heating. The rest of the northern Philippines and the central Philippines usually have no more than 5 days with thunderstorms in April.

Temperature. The Philippines experience little temperature change all year. The annual range of temperatures is largest in the northern Philippines at 6 Fahrenheit (3 Celsius) degrees and least in the southern Philippines at 2 Fahrenheit (1 Celsius) degrees. December, January, and February are usually coolest. April is one of the warmest months due to less cloud cover. Since western Luzon and the western islands of the central Philippines have the least cloud cover, the temperatures there rise slightly more than in the remainder of the islands. Temperatures in the Philippines vary more with elevation than with latitude. The absolute maximum temperature ever recorded in the Philippines, 108° F (42°C), occurred in Cagayan Valley of northern Luzon during April.

During January, temperatures generally are lowest in the north and east and highest in the west and south. Figure 3-8 shows average highs range from 77°F (25°C) in the Batan Islands to 90°F (32°C) along the southern coast of Mindanao. The eastern coast of Luzon shows the cooling effect of the northeast monsoon with some of the cooler temperatures in the archipelago. The mean highs there average 79° to 81°F (26° to 27°C); extreme highs can reach 97° to 100°F (36° to 38°C). Average highs of 86°F (30°C) are common throughout the western parts of the archipelago, especially the west coast of northern Luzon. Extreme highs of 100°F (38°C) are possible there. Higher elevations have the lowest temperatures. In the western mountains of northern Luzon, average highs reach 72°F (22°C) at about 5,000 feet (1,500 meters); the extreme high in January is about 86°F (30°C).

Freezing temperatures are unknown in the Philippines except at elevations above 9,000 feet (2,735 meters) in the Cordillera Central Mountains of Luzon during cold surges. January lows are typical of the coldest months during the northeast monsoon (Figure 3-9). Average lows range from 70° to 75°F (21° to 24°C) in northern Luzon to 74° to 79°F (24° to 26°C) from southern Luzon south. Extreme lows are 59° to 61°F (15° to 16°C) in northern Luzon and 63° to 68°F (17°

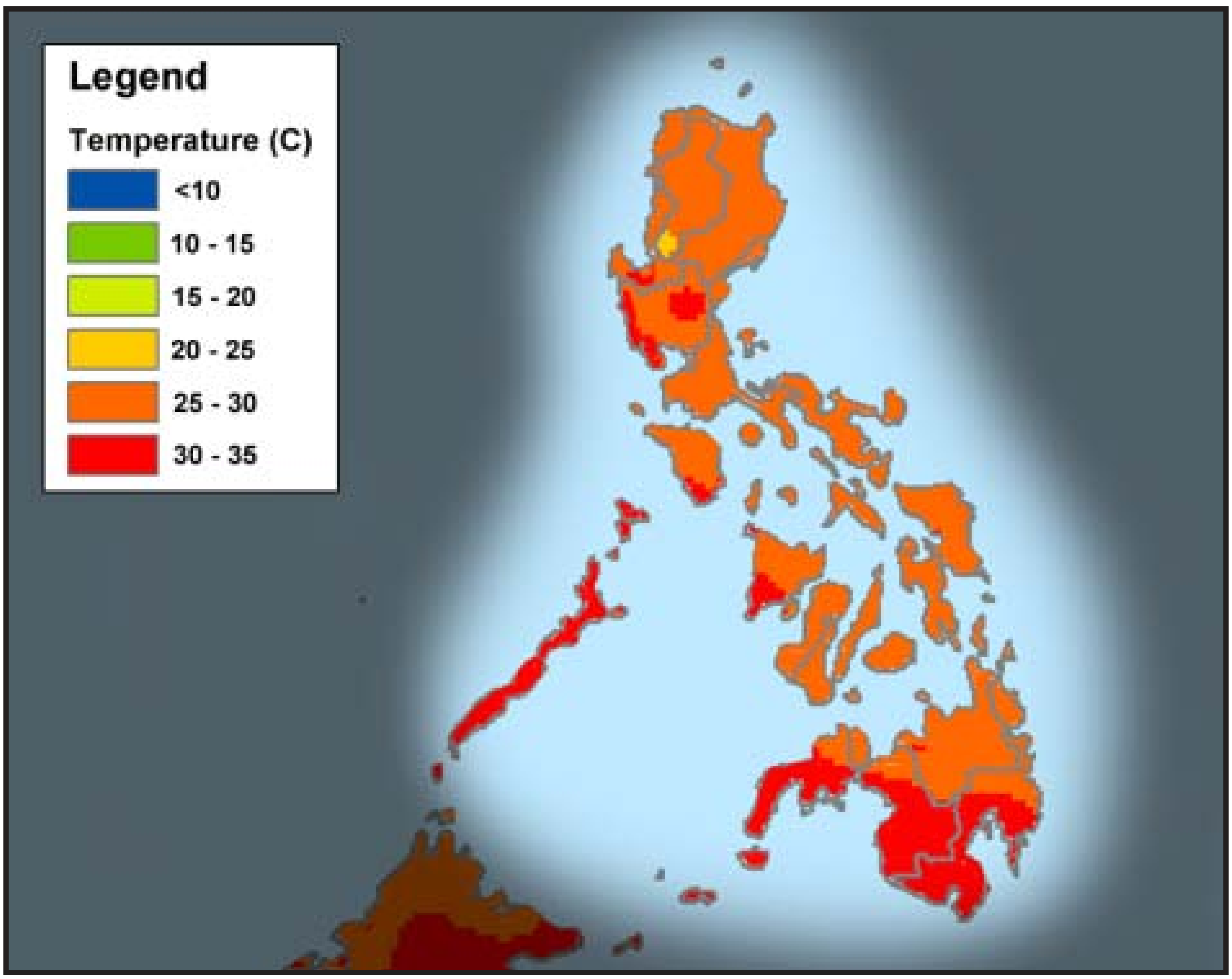

Figure 6-9. January Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all daily high temperatures for the coldest month of the northeast monsoon. Daily high temperatures are often higher than the mean.

to 20°C) elsewhere. In the mountains, lower temperatures prevail. In northwestern Luzon, the average low at 5,000 feet (1,500 meters) is 55° to 60°F (13° to 16°C) and the temperature can occasionally go as low as 45°F (7°C). On Mindanao, low temperatures at an elevation of 2,000 feet (600 meters) in the north central part of the island average 65° to 70°F (18° to 21°C) and can go as low as 55° to 60°F (13° to 16°C).

By April, one of the warmest months of the year, temperatures increase more in the north than elsewhere. Average highs range from 86°F (30°C) in the north and along the east coasts to 90°F (32°C) in the south and southwest. The west coast of northern Luzon and the interior plains and valleys of northern Luzon have the highest temperatures in April. Average highs there are 93° to 95°F (34° to 35°C). At 5,000 feet (1,500 meters) in northwest Luzon, the average high in April is cooler at 77°F (25°C). On Mindanao, at 2,000 feet elevation in the north central mountains, average April high temperatures are 84°F (29°C) and extreme highs can reach 91°F (33°C). The average lows in April are not very different from those in January except in northern Luzon warm; they range from 74° to 79°F (24° to 26°C), much the same temperature range as the rest of the Philippines with warmer temperatures south and west and the cooler temperatures north and east. The extreme lows in April range from 64°F (15°C) to 73°F (23°C).

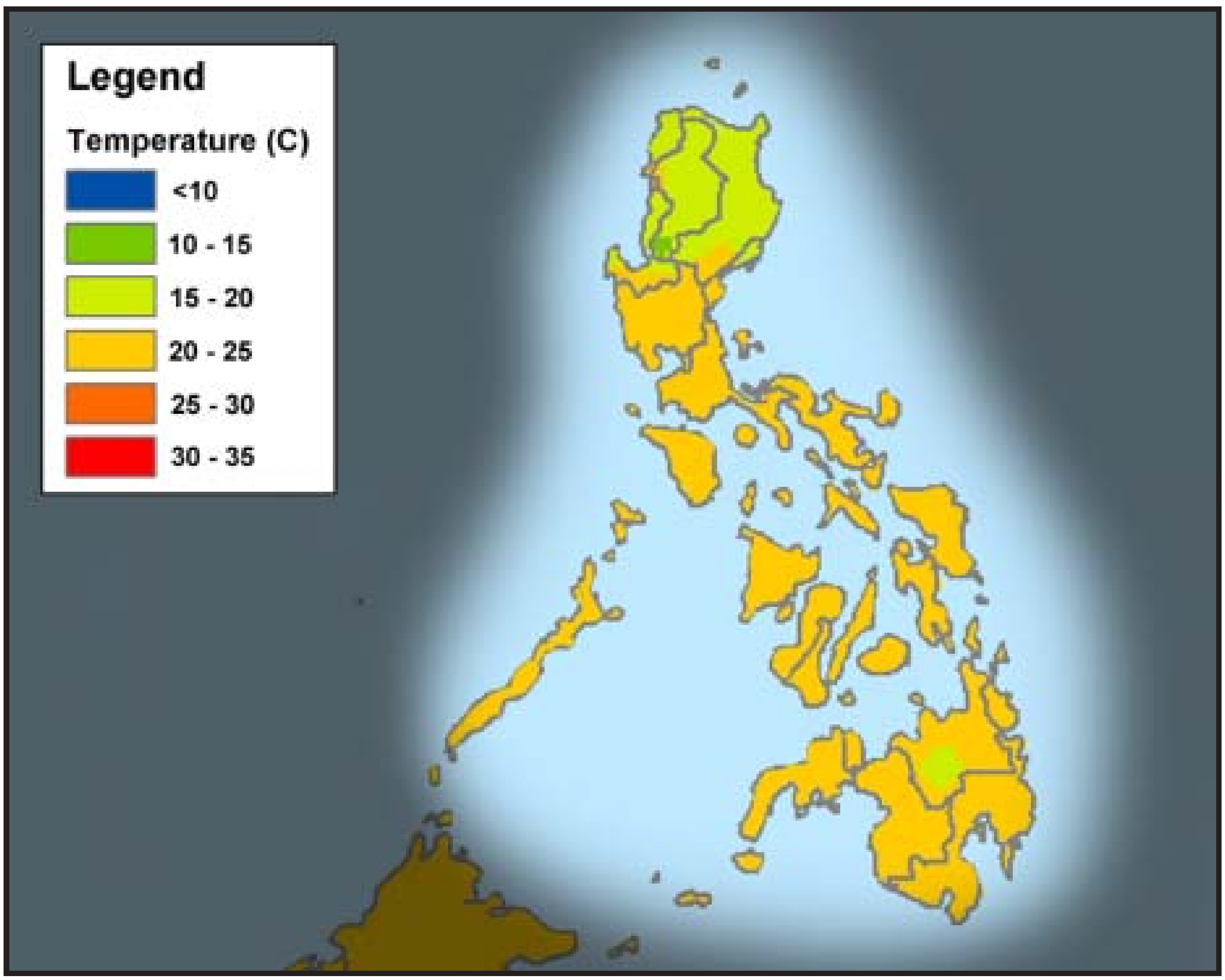

Figure 6-10. January Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all daily low temperatures for the coldest month of the northeast monsoon. Daily low temperatures are often lower than the mean.

Hazards.

Aircraft Icing. Icing is much more likely in the southwest monsoon than in the northeast monsoon as the clouds have greater vertical development and thunderstorms can penetrate the tropopause. Icing can extend from the freezing level, 16,500 feet, to 27,000 feet.

Floods. Severe flooding occurs every year due to heavy rains with typhoons, tropical storms, easterly waves, and thunderstorms.

Turbulence. Most turbulence is caused by thunderstorms and typhoons. The rugged terrain contributes mechanical turbulence, and there is occasional thermally-induced convective turbulence over the plains.

Typhoons. The northern Philippines has the highest frequency of tropical storms and typhoons in the world. The season extends from May through December and the frequency is highest during August and September. The average tracks of these storms cross northern Luzon and the Batan Islands during July through September. They cause tremendous loss of life and property in the Philippines. Depending on their track, they affect the weather for 1-7 days.

General Weather. Southwest monsoon weather is cloudy, hot and humid with frequent rain showers and thunderstorms. The North Pacific trade winds, the NETWC, the southwest monsoon airmass, tropical cyclones and easterly waves all affect the weather to varying degrees at different times. Fronts only affect the Philippines during the northeast monsoon and very early or late in the southwest monsoon season.

The NETWC affects the weather over the Philippines during this season. When it is south of the area, the trade winds prevail and fair weather occurs. This happens before the NETWC begins to move northward across the Philippines. As the NETWC moves northward across the Philippines, a band of unstable weather with showers and thunderstorms accompanies it. When well developed, the NETWC also has stratiform clouds with continuous rain. South of the NETWC, the southwest monsoon transports maritime equatorial air over the area. This causes cloudy weather with intermittent rain along the west coasts and less cloudiness with scattered showers inland. Except for typhoons, the NETWC causes the worst weather. Strong winds aloft cause squalls. Easterly waves and tropical cyclones can exacerbate these bad weather conditions. Easterly waves affect the Philippines about twice per week and cause extensive cloudiness along the east coast. The waves interact with higher terrain and cause continuous rain that can last 2 to 3 days.

Tropical cyclones occur most frequently during this season and peak in August and September. The season extends from May through December. The average tracks of these storms cross northern Luzon and the Batan Islands during July through September. They cause tremendous loss of life and property in the Philippines. Depending on the track, they affect the weather for 1-7 days.

Sky Cover. Cloudiness increases from the beginning of the season until the southwest monsoon reaches its peak in July or August, then starts to decrease at the end of the season as the NETWC recedes southward. May cloud cover averages broken conditions. In July and August, cloudiness averages broken in northeast Luzon to overcast near the coast of northwest Luzon. In October, cloud coverage averages broken along the east and west coasts of the northern Philippines and the west coast of the central Philippines. Elsewhere, it averages broken to overcast. The west coast has the most cloud during the southwest monsoon due to orographic lift. Because the southwest monsoon flow extends to 33,000 feet, and the subsidence inversion is at 13,000 feet, convective clouds can develop and extend to higher elevations than during the northeast monsoon. The unstable conditions and terrain-induced orographic lifting cause convective clouds that break through the inversion. Thunderstorms often penetrate the tropopause (52,000 feet). Because the mountains along the west coasts are not high enough to totally block these clouds, they spread eastward across the islands. Middle and high clouds are also more prevalent than during the northeast monsoon.

Ceilings below 3,000 feet (Figure 6-11) occur more frequently along the exposed windward coasts and on the windward slopes of the mountains than at other locations. They occur more in the late morning and late afternoon than early morning. In northern Luzon, ceilings less than 3,000 feet occur in the mountains of northwestern Luzon 40-60 percent of the time in the morning from June to September and up to 85 percent of the time in late afternoon. The protected inland Cagayun Valley of northern Luzon has them as often as 50 percent of the time in the early morning and 60 percent of the time in the late afternoon. Ceilings there occur more in October as the northeast monsoon starts to affect the area and the northeasterly flow brings the moisture into the valley. Elsewhere in the northern Philippines, ceilings less than 3,000 feet generally occur less than 20 percent of the time in the afternoon to early evening and 10-15 percent of the time or less in the morning. In October, eastern locations tend to show an increase in cloudiness and ceilings less than 3,000 feet. In the central and southern Philippines, ceilings below 3,000 feet occur up to 15 percent of the time at windward locations in the early morning and 25 percent of the time in the afternoon during July to August. Less exposed locations have the ceilings below 3,000 feet less than 10 percent of the time.

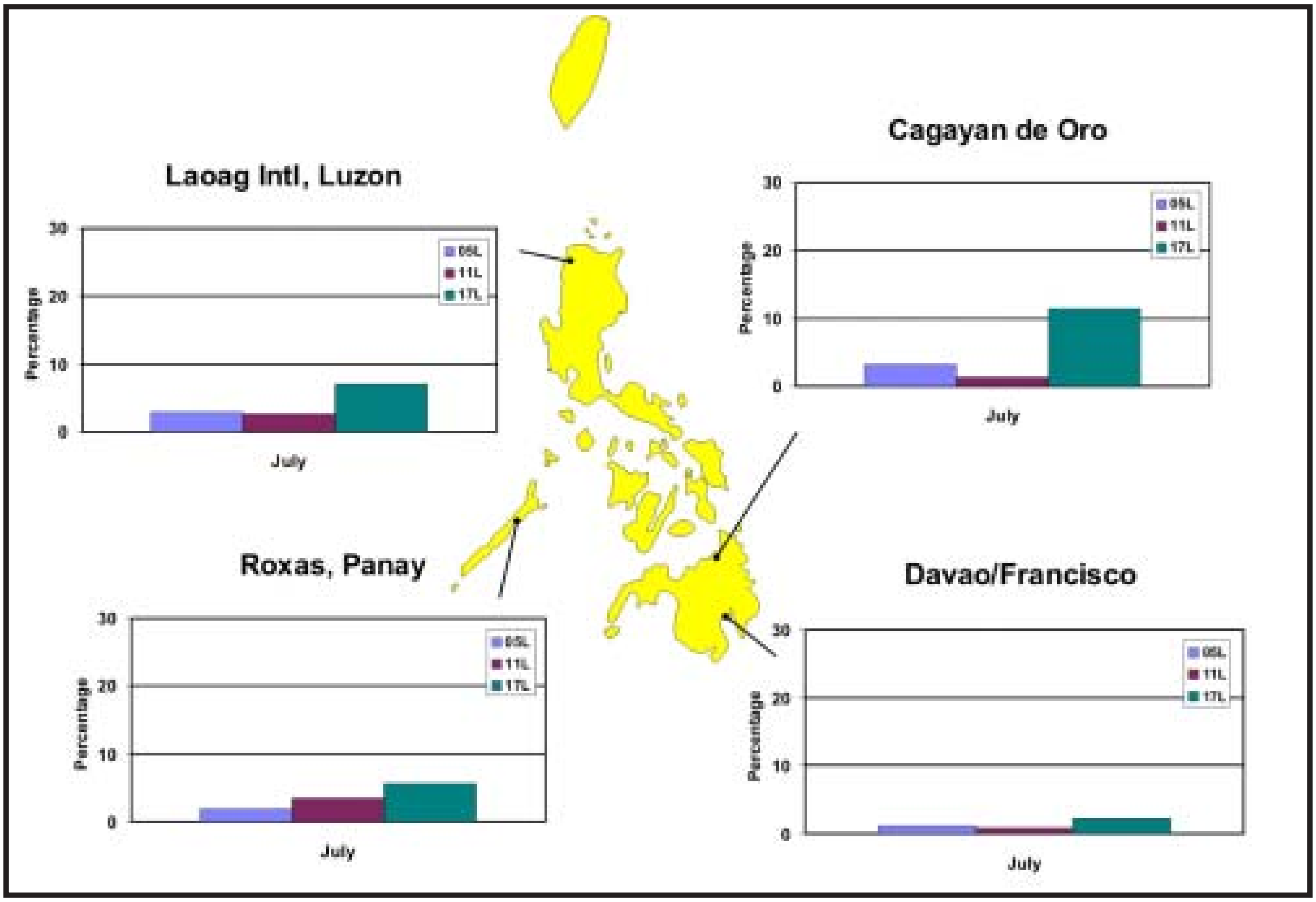

Figure 6-11. Southwest Monsoon Percent Frequency of Ceilings Below 3,000 Feet . The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Fog occurs in the mountains in the evening and early morning, but the visibility is mostly good everywhere else and at other times of the day. Visibility less than 3 miles (4,800 meters) occurs mostly in the mountains and with heavy rain. Visibility less than 4,800 meters occurs less than 5 percent of the time everywhere except in the mountains (see Figure 6-12). In the mountains of northwest Luzon, visibility below 4,800 meters occurs 50 percent of the time in the evening and early morning in August due to fog that occurs as often as 28 days of the month. By late morning, the visibility improves so that visibility below 4,800 meters occurs 30 percent of the time in August, the worst month. On Mindanao, the mountain location of Malaybalay has visibility less than 4,800 meters less than 20 percent of the time in July in the early morning. Haze, common in the Philippines, generally does not cause the visibility to go below 4,800 meters.

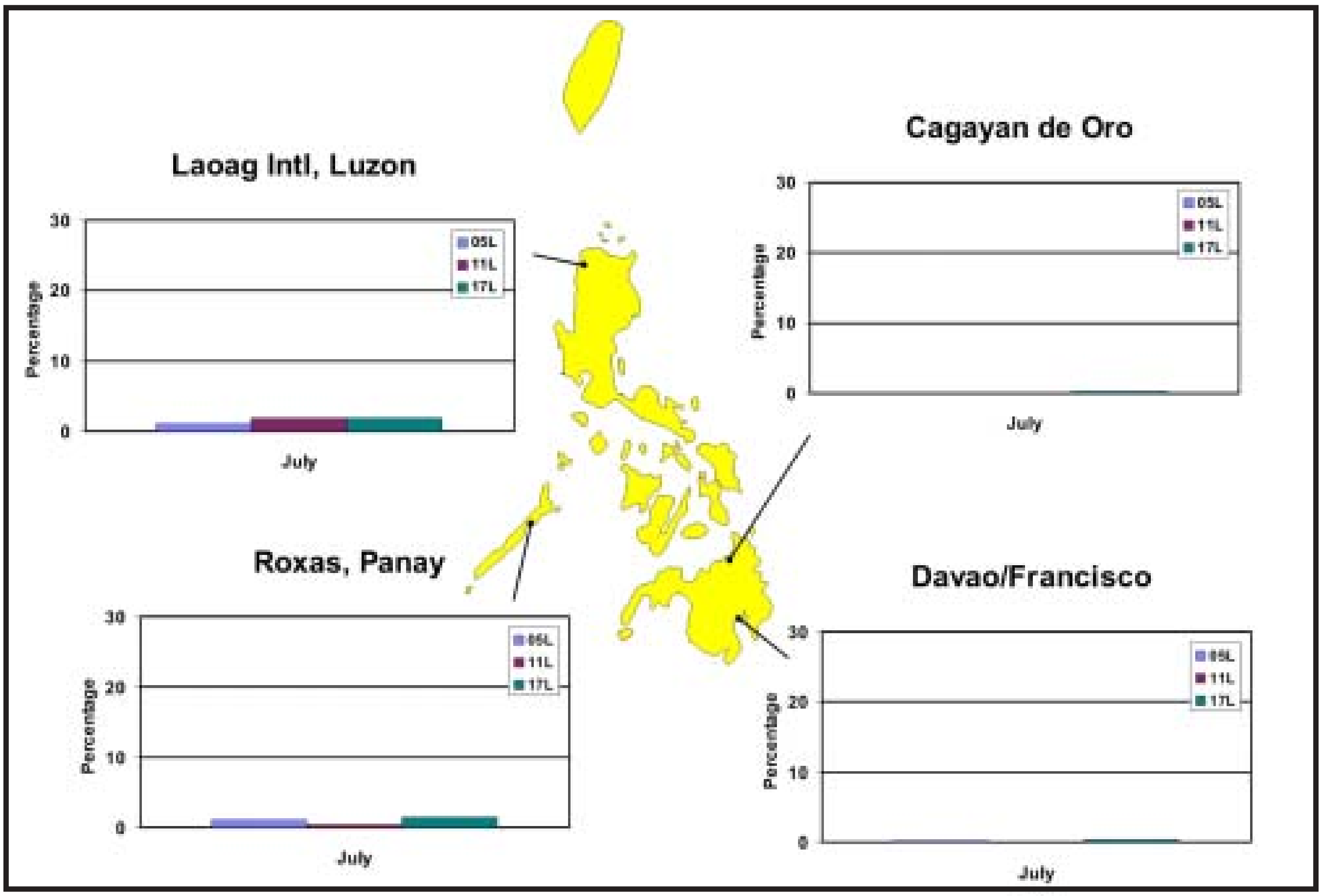

Figure 6-12. Southwest Monsoon Percent Frequency of Visibility Below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percent of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Mean winds from the southwest at an average of 4-6 knots, especially near the west coasts, but may be from the west or south. Topography has a strong influence on the winds. Land/sea breezes occur on the coasts. Along the west coasts, the southwesterly monsoon flow enhances the sea breeze and damps the land breeze, so the strongest surface winds are along and near the west coasts. The sea breeze starts by late morning and peaks in late afternoon while the land breeze begins once the land cools after sunset and peaks near sunrise. The wind roses for July (shown in Figure 6-13) show winds at specific sites. No inferences can be made about the winds at other locations with these winds because of differences in the terrain. Although not common in the Philippines, foehns occur on the lee side of the mountains where the surface flow is nearly perpendicular to the flow. Luzon and Mindanao are most vulnerable. In addition, mountain/valley breezes are possible in the mountains. By October, the northeasterly prevailing winds of the North Pacific trade winds return except in the southern Philippines where south winds still prevail. Winds over 28 knots are not frequent in the Philippines, but because the southwest monsoon season is also the season for typhoons and thunderstorms, the record winds exceed 90 knots at many locations.

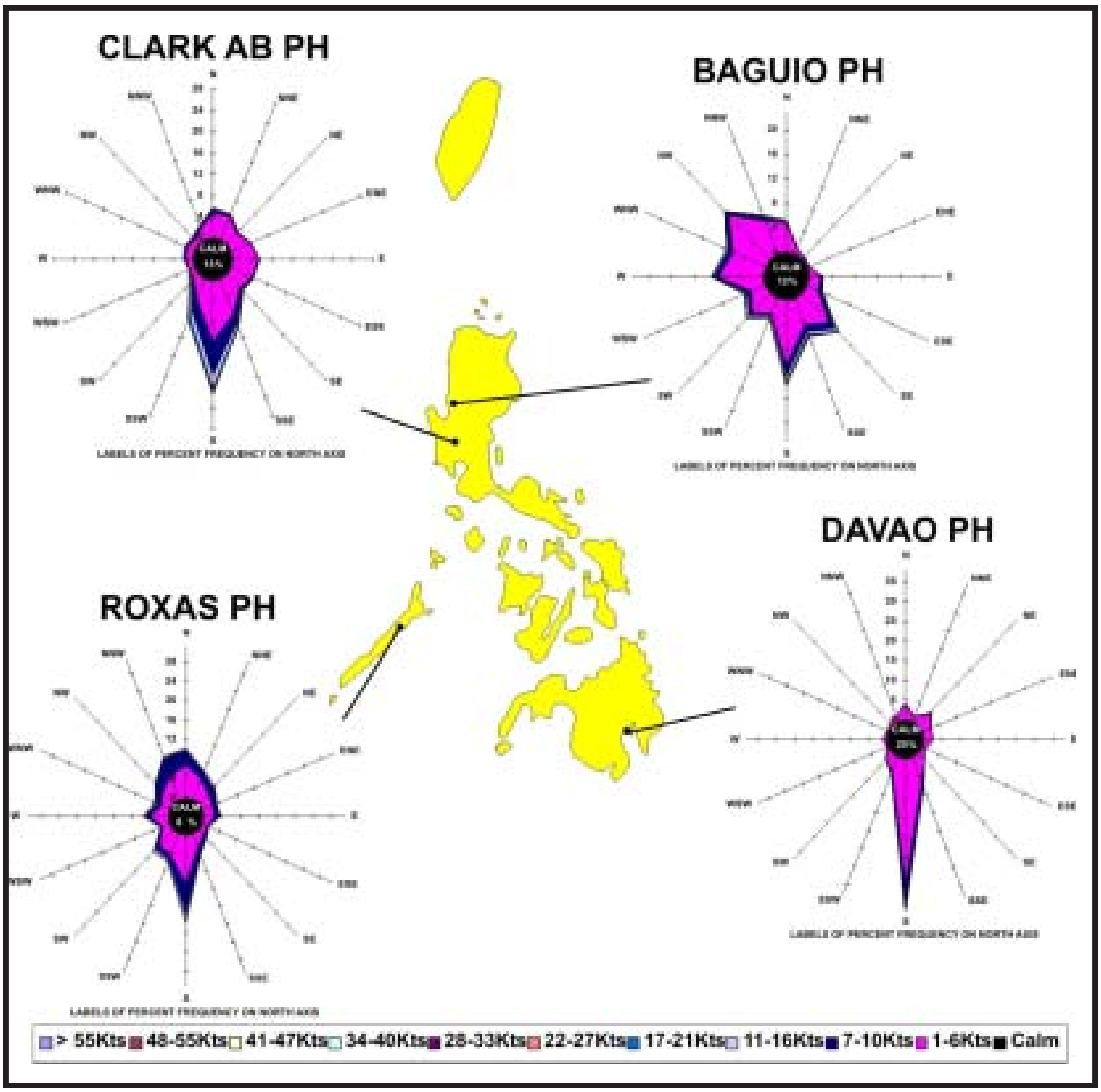

Figure 6-13 July Surface Wind Roses. The figure shows the prevailing wind directions and range of speeds based on frequency and location.

Upper Air Winds. The July 850-mb winds at Laoag (Figure 6-14) are mainly from the south through southwest. The strongest winds are from the south-southwest at up to 45 knots. At and above 700 mb, easterlies prevail. Winds at 700 mb average 20 knots or less with speeds up to 40 knots possible with east through southeast winds. At 300 mb, winds average 60 knots or less from the east-northeast through east. By October, 850-mb winds become easterly at 15 knots or less with speeds of 60 knots possible. Winds at 700 mb and above are easterly. Compared to July, more westerly winds are evident at 300 mb in October.

Over the central and southern Philippines, southwesterly to westerly flow prevails at 850 mb, and the North Pacific trade winds prevail at and above 700 mb. The 850-mb winds are from the west-southwest through west-northwest at average speeds below 30 knots and as much as 45 knots. At 700 mb, the prevailing east-northeast through east-southeast winds are usually under 20 knots with maximum speeds of 40 knots. Light southwesterly winds are also evident at 700 mb. At 500 mb and 300 mb, the easterlies are light, usually under 25 knots at 500 mb and 30 knots at 300 mb.

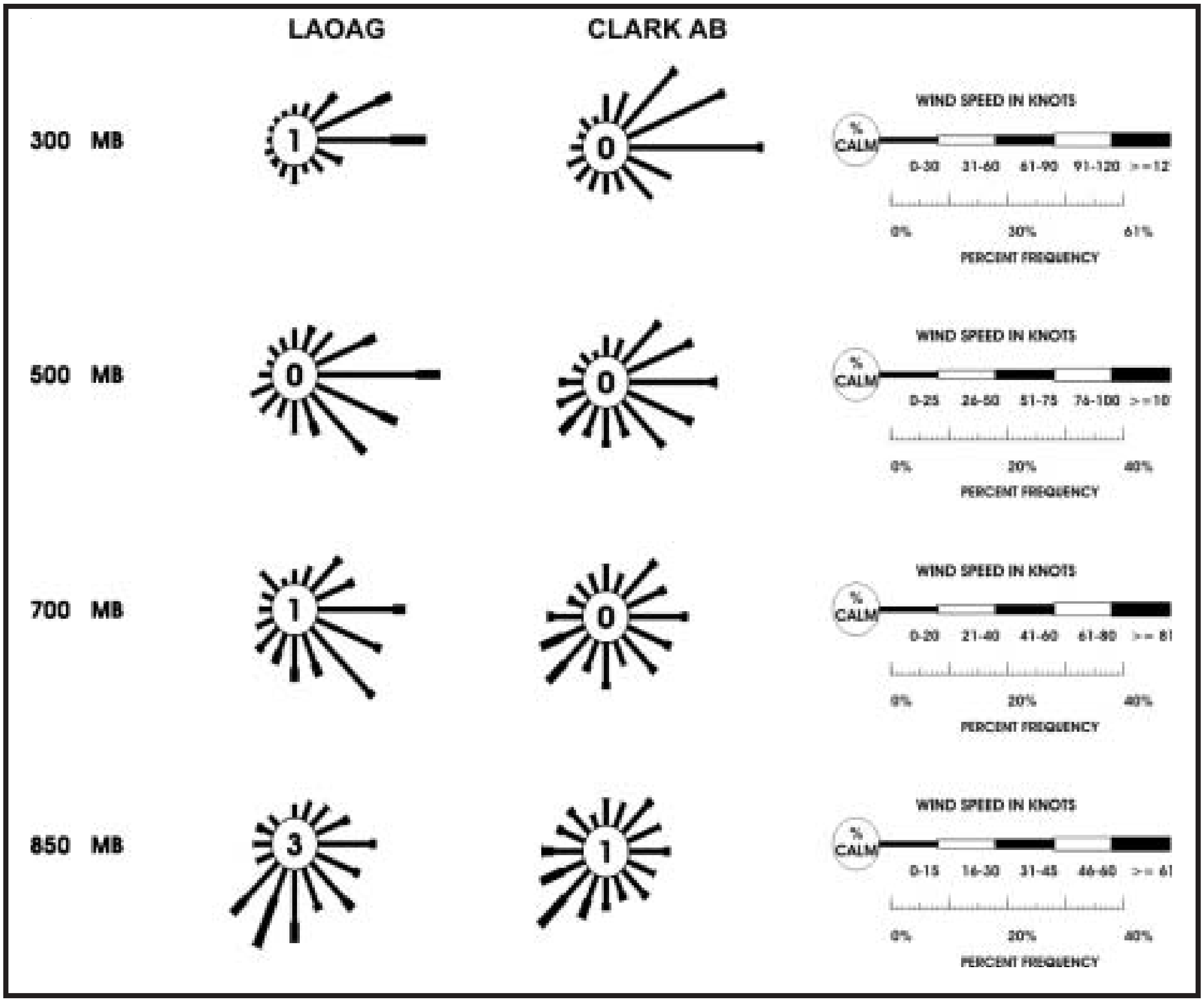

Figure 6-14. July Upper-Air Wind Roses. The wind roses depict the wind speedand prevailing direction averaged for all hours at the standard pressure surfaces between 850 and 300 mb at Laoag and Mactan International.

Precipitation. The southwest monsoon season brings the rainy season in the tropics, but only the western Philippines experiences this defined rainy season. Much of the rest of the Philippines is rainy year-round. The eastern coasts receive the most rain on an annual basis; most of that occurs during the northeast monsoon and in the transition periods when the North Pacific trade winds prevail. The east coast also receives the brunt of the precipitation from tropical systems. Luzon, the Babuyan Islands, and the Batan Islands are most likely to be hit by typhoons.

During this season western Luzon receives the most rainfall, over 20 inches (500 mm) per month (Figure 6-15), and over 40 inches (1,000 mm) in northwest Luzon. The Philippine eastern coasts get the least rainfall, 5-10 inches (125-250 mm). Northwestern Luzon also experiences some of the heaviest 24-hour rainfalls during the southwest monsoon. As much as 46 inches (1,170 mm) has fallen in the mountains in one 24-hour period in July. Coastal sites on northwest Luzon have had over 20 inches (500 mm) in 24 hours. The western coast of the northern Philippines and the central Philippines can have as much 50 inches (1,270 mm) or more of rainfall during July. Some sites along the east coast of southern Luzon and the central Philippines have received 13-18 inches (325-450 mm) in 24 hours during this season due to tropical depressions or easterly waves. This part of the east coast receives its maximum 24-hour rainfalls during the southwest monsoon season, but its highest average monthly precipitation occurs during the northeast monsoon. During July, the highest

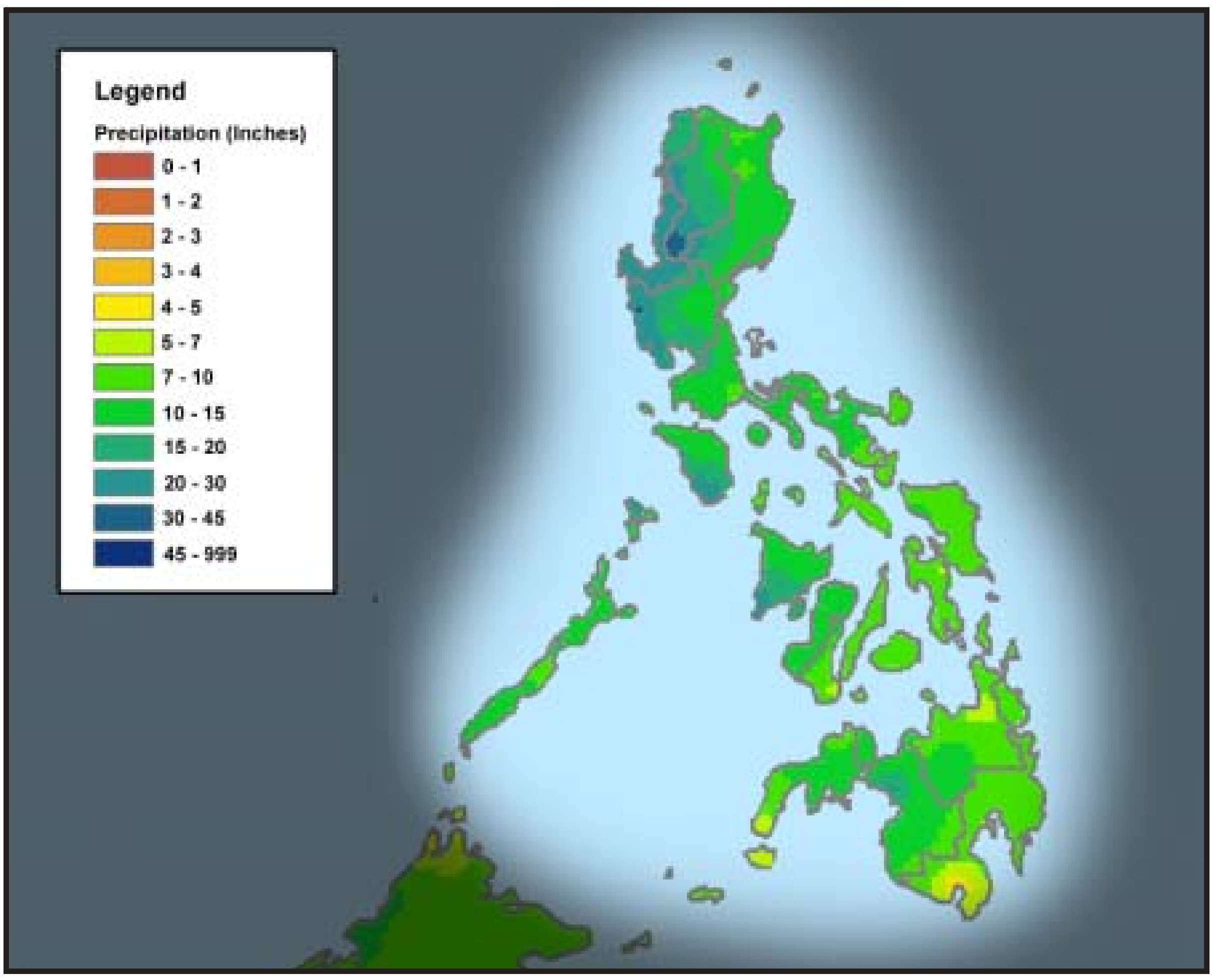

Figure 6-15. July Mean Precipitation. The figure shows precipitation in the Philippines for July when the southwest monsoon is at its peak.

rainfall in this area is 10-20 inches (250-500 mm), much less than the greatest monthly precipitation amounts during the northeast monsoon. By October, the rainfall pattern changes as the southwest monsoon weakens and the northeast monsoon begins to build. Northern and eastern Luzon have the greatest monthly rainfall of over 50 inches (1,270 mm).

The region averages 19 rain days per month in locations that get the most rainfall in July and August, such as northwestern Luzon, the western islands of the central Philippines and the Mindanao mountains. The number of rain days varies with terrain, exposure to southwest monsoon flow, and the occurrence of tropical cyclones. The fewest occur in May and June and in September and October but only marginally less than the rest of the season. During July and August, 13-25 rain days occur per month (Figure 6-16).

Thunderstorms occur from 5 to more than 20 days per month. The Luzon western coastal mountains and the Mindanao mountains have thunderstorms often in July, 15-20 days and 10-25 days respectively. The east coast of Luzon has the fewest, from fewer than 5-10 days. The Mindanao southern coast has fewer than 5 thunderstorm days in July. By October, thunderstorm days decrease to 5 days or fewer over northern Luzon. Much of the central and southern Philippines continue to experience 10 or more thunderstorm days in October. When the NETWC is in the vicinity of the Luzon Straits, thunderstorms are localized along the west coast of Luzon and over the mountain areas in late afternoon and early evening. When the NETWC lies over southern Luzon, thunderstorms are common in the afternoon and early evening over most of Luzon.

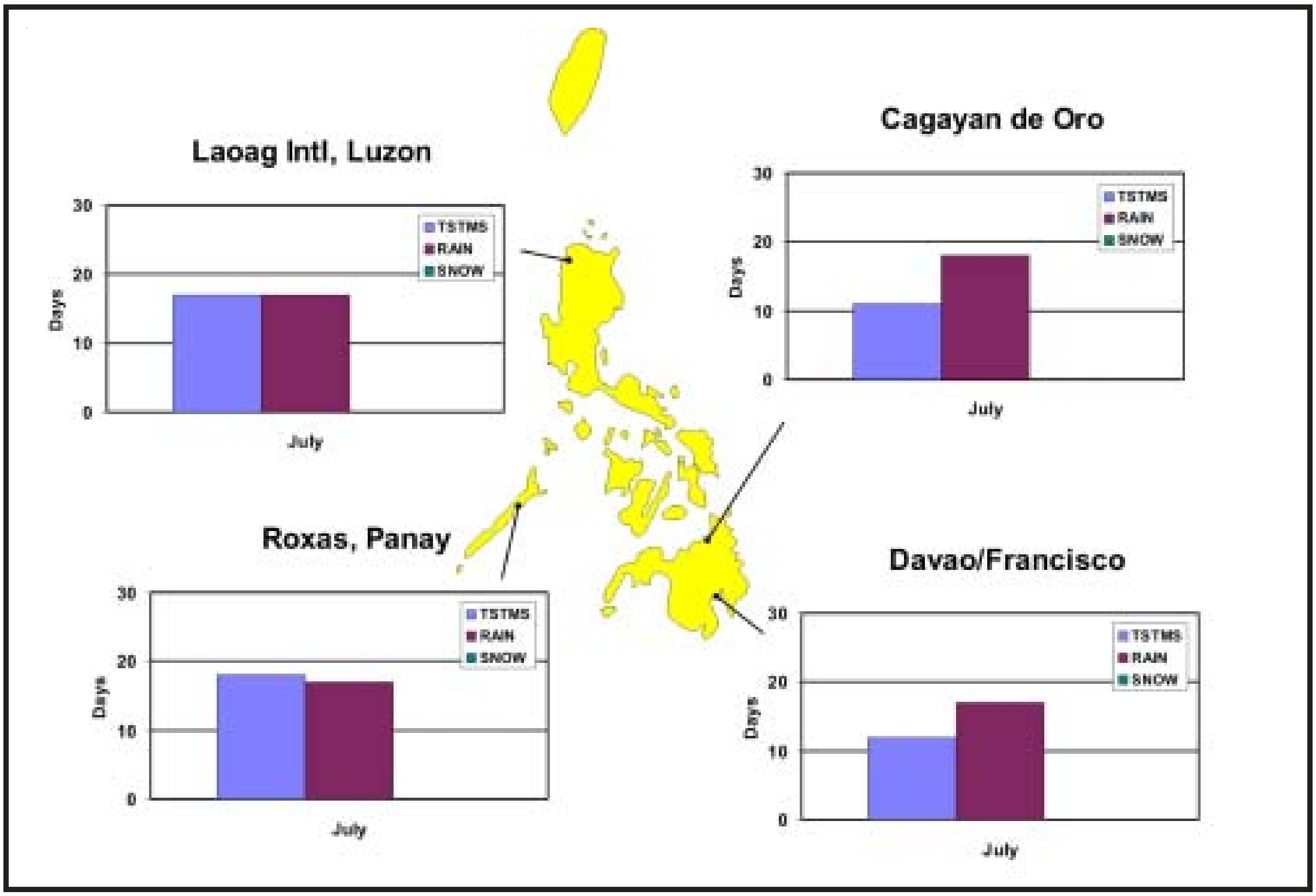

Figure 6-16. Southwest Monsoon Mean Precipitation and Thunderstorm Days. The graphs show the average summer occurrences of rain and thunderstorm days for representative locations in the Philippines.

Temperatures. Although temperatures are fairly constant year-round in the Philippines, they peak in April, May, and June. Slightly less cloudiness in those months allows more surface heating. During the southwest monsoon, the average temperature in the northern and central Philippines is 83° F (28° C), and in the southern Philippines, it is 82° F (28° C). With very little annual variation in temperatures, temperatures are similar to those in other seasons, but slightly cooler than in April and May, the warmest months of the year. Temperatures average 81° to 82° F (27° to 28° C) in June through September.

Average highs in July are fairly uniform, between 86° F (30° C) and 90° F (32° C); see Figure 6-17. It is cooler in the mountains. In northwest Luzon, the average high is about 75° F (24° C) at 5,000 feet (1,500 meters). On Mindanao, the average high is 82° F (28° C) at 2,000 feet (600 meters) elevation. Extreme highs top 104° F (40° C), except in the mountains where extreme highs are slightly cooler. Average lows are also fairly uniform (Figure 6-18). Temperatures vary between 75° F (24° C) and 79° F (26° C) except in the mountains where it is cooler and the southwest coast of Mindanao where it is warmer. The July average low in the mountains of northwest Luzon is 64° F (18° C). On Mindanao, the mountains have an average low of 70° F (21° C). Extreme lows in July never go below 60° F (15° C) at 5,000 feet (1,500 meters) elevation in northwest Luzon and temperatures at lower elevations are warmer.

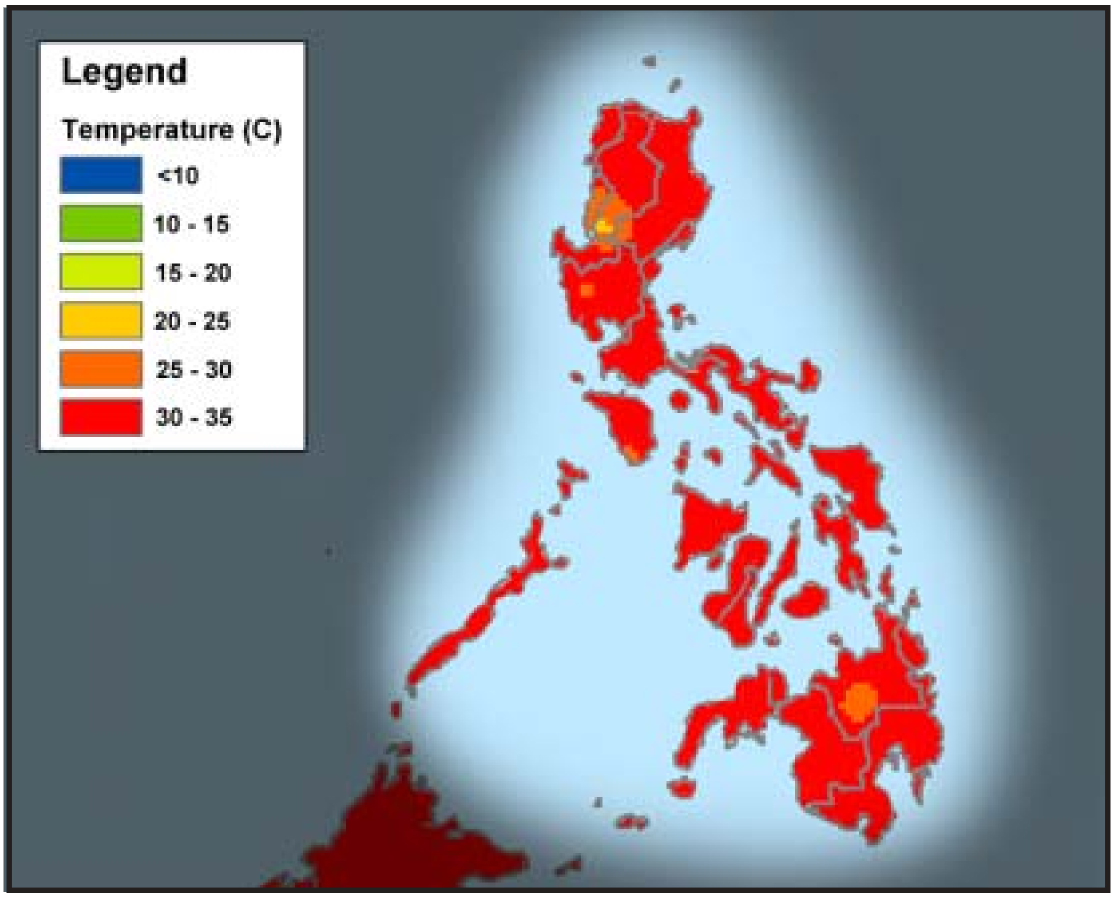

Figure 6-17. July Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all daily high temperatures for the warmest month of the southwest monsoon. Daily high temperatures are often higher than the mean.

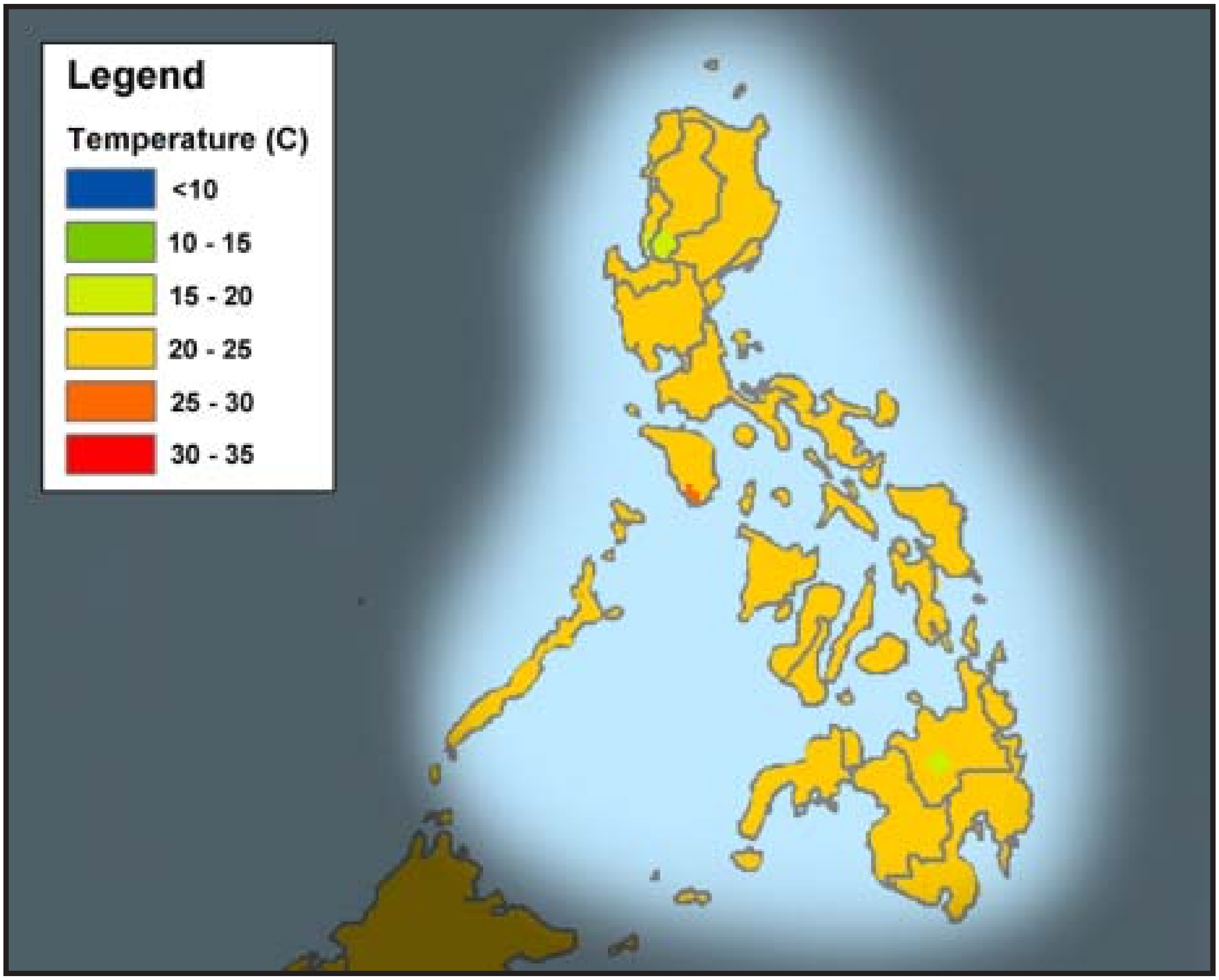

Figure 6-18. July Mean Minimum Temperatures (°C). These temperatures represent the average of all daily low temperatures for the warmest month during the southwest monsoon. Daily low temperatures are often lower than the mean.

Hazards.

Aircraft Icing. Icing is much more likely in the southwest monsoon than in the northeast monsoon as the clouds have greater vertical development and thunderstorms can penetrate the tropopause. Icing can extend from the freezing level, 16,500 feet, to 27,000 feet.

Floods. Severe flooding occurs every year due to heavy rains with typhoons, tropical storms, easterly waves, and thunderstorms.

Turbulence. Most turbulence is caused by thunderstorms and typhoons. The rugged terrain contributes mechanical turbulence, and there is occasional thermally-induced convective turbulence over the plains.

Typhoons. The northern Philippines has the highest frequency of tropical storms and typhoons in the world. The season extends from May through December and the frequency is highest during August and September. The average tracks of these storms cross northern Luzon and the Batan Islands during July through September. They cause tremendous loss of life and property in the Philippines. Depending on their track, they affect the weather for 1-7 days.

Chapter 7

THE ISLANDS

This chapter describes the topography, major climate controls, special climatic features, and general weather (by season) for the ocean islands of the western Pacific basin. There are three sections; each covers an island group: north, central and south. The north island group consists of the Mariana Islands. The central island group consists of all islands and atolls east of the *Philippines* to 165° E and between the equator and 10° N. Included are Palau and the islands of the Federated States of Micronesia. The south island group consists of all islands between New Guinea and 165° E between the equator and the southern boundary of the region (approximately 12° S). Included are the Solomon Islands, Bougainville Island, New Ireland, and New Britain.

Figure 7-1. Western Pacific Islands. The figure shows the western Pacific Islands in relation to other countries in the western Pacific region.

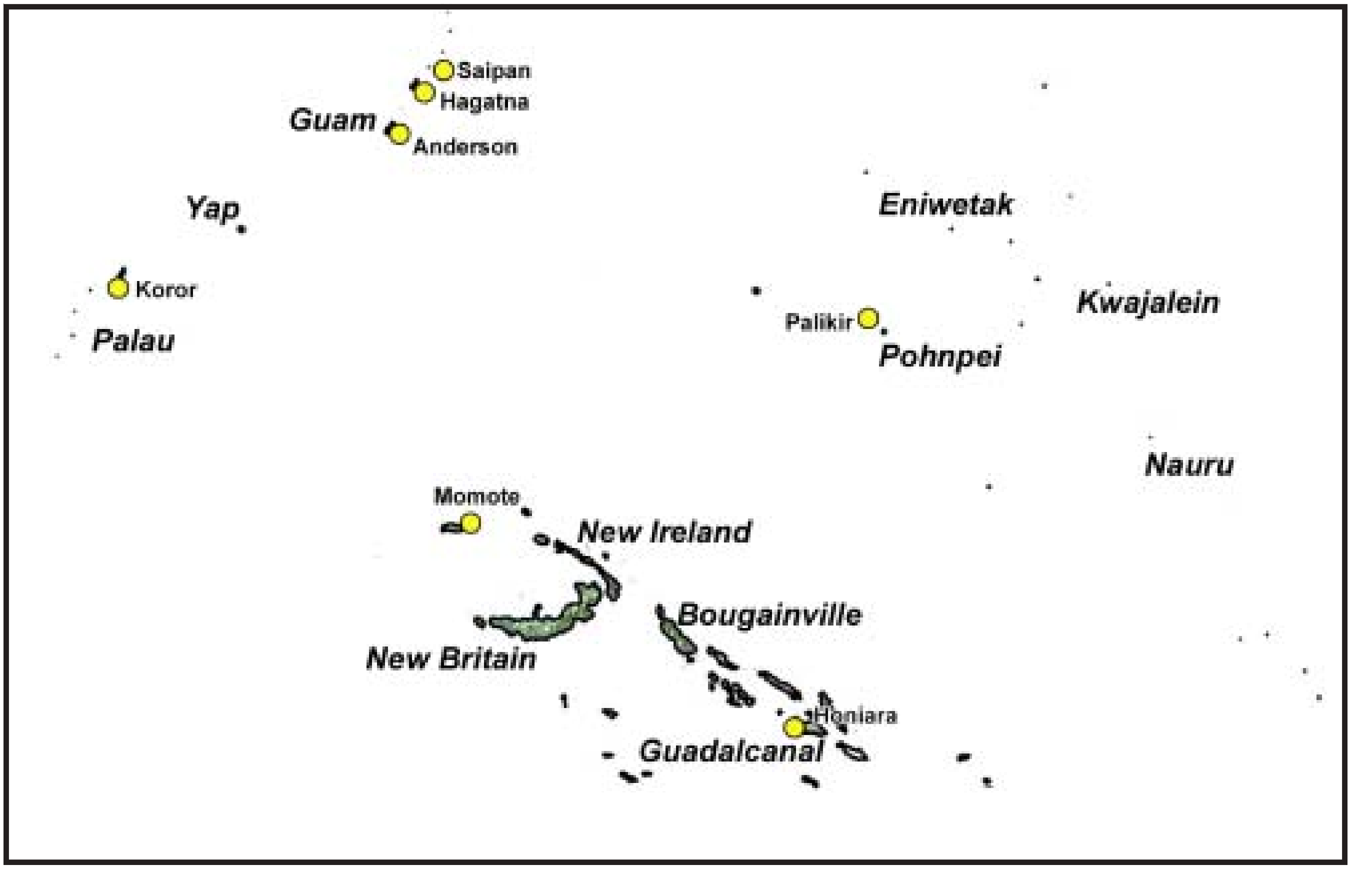

Figure 7-2. Topography of the Western Pacific Islands.

TOPOGRAPHY.

North Island Group. The north island group consists of all the islands north of 10° N and east of the Philippines. The northern limit is along the 21st parallel between 123° E and 150° E. The eastern limit is a line that stretches southeast from 21° N, 150° E to 10° N, 163° E. The Mariana Islands are in this group. This is a string of islands that extends about 510 miles (820 km) from Guam in the south, to Farallon De Pajaros in the north (see Figure 7-1). All but one of the islands are made up of volcanic basalt. The lone exception is Farallon de Medinilla, which is a coral island. Islands in the northern part are small and purely volcanic in nature. Those in the south have volcanic bases covered with coral limestone. Some of the islands have coral reefs.

Guam. The largest and southernmost island in the Marianas chain, Guam is 28 miles (45 km) long and 4 to 8 miles (6 to 12 km) wide. Guam is shaped like a bow tie and has three distinct topographic regions. The northern third of the island lacks surface streams and is a plateau of rolling hills bounded by steep cliffs that fall either directly to the sea or to narrow beaches. The plateau is 300-600 feet (90-180 meters) above sea level. The southern half of the island is a complex of low volcanic mountains and valleys where small streams and several waterfalls are found. The highest point of the island is Mount Lamlam at 1,334 feet (407 meters). The middle of the island is a narrow waist between the northern and southern regions. It has rolling hills with elevations generally under 200 feet (60 meters).

Rota. Nearly 47 miles (76 km) north of Guam, Rota is 10.5 miles (17 km) long and 3 miles (5 km) wide. The terrain on Rota slopes upward from northeast to southwest. Mount Manira, in the southern part of the island, has the highest elevation at 1,625 feet (496 meters).

Aguijan. This uninhabited island lies between Rota and Tinian. There are steep cliffs on all sides of this island.

Tinian. Located 6 miles (9.6 km) south of Saipan, it is 10.5 miles (16.9 km) long by 5 miles (8 km) at its widest point. A ridge runs along the western side of the island with elevations from 440 feet (134 meters) in the north to 584 feet (178 meters) in the south.

Saipan. At 12.5 miles (20.1 km) long and 5.5 miles (8.9 km) wide, Saipan is the second largest island in the Marianas. The southern end of the island is fairly level while the northern two-thirds is mountainous. The highest point on the island is Mount Tapotchau (1,554 feet/474 meters) in the middle of the island. A secondary high point is located at the northern end of the island with an elevation of 915 feet (279 meters). Between these two points lies a ridge with an average elevation of 500 feet (150 meters).

Farallon De Medinilla. This small, coral island lies 52 miles (83.4 km) north of Saipan. It is a tableland with low vertical sides covered by bush and grass.

Anatahan. Located about 86 miles (139 km) north of Saipan, this tiny island has an 2,582 foot (788 meter) extinct volcano. Inside its crater are two peaks with a grass covered flat field. The island has steep slopes furrowed by deep gorges. The coast line is precipitous with sandy beaches on the north, west, and southwest.

Sarigan. This island is an extinct volcano located about 109 miles (176 km) north of Saipan. The highest point of this uninhabited island (1765 feet /538 meters) is at its southern end. The island has numerous ravines and valleys with dense tropical vegetation. It is surrounded by vertical cliffs, which make landings difficult.

Guguan. This tiny island, about the size of Sarigan, is located about 150 miles (241 km) north of Saipan. An active volcano lies at its southern end. The height of the volcano is approximately 942 feet (287 meters). The west wall of the volcano has collapsed and a new cone has built up above the wall of the old one. There are deep ravines between the two peaks. Smoke and large quantities of sulphur sometimes spew from the volcano. The sulphur has given the mountain the appearance of having a snow cap from a distance. The coast is bordered by steep basaltic rock with high ridges and deep rain eroded gorges. Sometimes a lake forms within the crater during the rainy season. The island is uninhabited.

Alamagan. This uninhabited island lies about 168 miles (271 km) north of Saipan. It has an extinct volcano with a large crater at its 2,441 foot (744 meter) summit. The volcano is on the northeastern part of the island. The island's west side is cut by deep gorges covered with high savanna grass. The southeast side is a steep slope of bare lava. There are deep valleys with caves. Coconut palms grow on the gradual slopes. Warm, fresh water springs are on the northwest part of the island.

Pagan. Located about 199 miles (321 km) north of Saipan, this island has three active volcanoes, one of which is separated from the others by a narrow one mile (1.6 km) wide and 2.5 mile (4 km) long plain. Pagan is about 10 miles (16.1 km) long and one to five (1.6 - 8.0 km) miles wide. It has the shape of an oblong barbell. One volcano on the south end of the island emits steam while one on the north end is often covered by a heavy sulfurous cloud. Brown ash covers the slopes of Mount Pagan (elevation: 1900 feet/580 meters). Two lakes lie at the base of the mountain. A series of vertical cliffs cut the island into two sections. The coast is rocky and unapproachable except on the shores of the eastern road stead and at Apaan Bay on the west coast. The island is lightly populated.

Agrihan. This uninhabited island lies about 236 miles (380 km) north of Saipan. It has a 3,166 foot (966 meter) high volcano near the middle of the island (last active in 1917). Agrihan has areas of gentle slopes near the shoreline on the southeast and southwest sides, and at the crater entrance on the north side. The rest of the island consists of steep slopes and deep gorges. The coast is rocky and steep with a landing beach on the southwest coast.

Asuncion Island. This tiny island is 300 miles (483 km) north of Saipan. It has a 2,812 foot (858 meter) volcano that rises steeply in the northeast portion of the island. A landing beach is on the southwest end.

Maug Islands. This is a group of three tiny islands 323 miles (520 km) north of Saipan. These islands are the remains of a partly submerged volcano that surround a deep and spacious harbor. The islands are bordered by steep cliffs.

Farallon De Pajaros. Approximately 363 miles (584 km) north of Saipan, this tiny island has an active volcano (elevation: 1,096 feet/334 meters).

Rivers and Drainage Systems. Permanent rivers are nonexistent in the Mariana Islands. Streams and creeks are water routes on the bigger islands, especially in the hilly and mountainous regions. Gorges, valleys, and ravines often become waterways in heavy rains.

Central Island Group. The central island group includes the Palau Islands and the Federated States of Micronesia. There are over 2,000 islands scattered in this area. All of the islands are small, and less than 100 are populated. These islands are broadly classified as high volcanic or low coral, and as continental or oceanic. The Palau Islands and Yap, in the western part of the region, are classified as high types of varying elevations. In the eastern part of the region, Chuuk (formerly known as Truk), Pohnpei and Kosrae are also high islands. They have maximum elevations of 1,453, 2,595, and 2,064 feet (443, 791, and 629 meters), respectively. The remainder of the islands in the region are low coral types that rise less than 10 feet (3 meters) above sea level. Some are single islands that have no reef or lagoon. Others are raised atolls with lagoons as well as their encircling reefs are fully exposed. Information on some of the islands follows.

Palau Islands. About 597 miles (960 km) east of the Philippines, the Palau Islands are the most westerly island group of the region. There are several hundred volcanic islands and a few coral atolls spread from north to south over 100 miles (161 km) from Kayangel Atoll to Anguar Island. It also includes Sonsorol, Palo Anna, Merir, Tobi and Helen Reef. The islands and atolls vary in size from small islands of coral limestone formation to Babeldoab, the main island. The terrain ranges from the high, mountainous terrain of Babelthuap to low coral islands usually surrounded by large barrier reefs. The highest point is Mount Ngerchelchauus, 804 feet (245 meters), in the northern half of Babelthuap.

Yap Islands. This island group lies midway between Guam and Palau. It consists of four large (Yap, Tamil-Gagil, Map and Rumung) and ten small islands. The islands are mostly low, rolling grass-covered hills. The highest elevation for the group is a 585 foot (178 meter) hill located on northern Yap.

Chuuk Islands. Formerly known as the Truk Islands, this group lies near 7° N, 152° E, it consists of 290 small coral and high volcanic islands scattered over a large lagoon. Except for the two largest islands, Moen and Toi, the islands are fairly level. Toi, the largest island, is fairly hilly in the eastern half with a northwest to southeast upward slope. The highest point on Toi is on the southern side of the island, 1,453 feet (443 meters). Moen, the second largest island, is roughly triangular in shape. Its highest point is Mount Teroken, which rises to 1,224 feet (373 meters).

Pohnpei. Also known as Ponape, this island group is made up of one large island and six inhabited atolls. Near 7° N, 158° E, Pohnpei is nearly circular and rises to an elevation of 2,595 feet (791 meters). The topography is a complicated system of ridges and valleys interlaced with small rivers and intermittent streams.

Rivers and Drainage Systems. A few small rivers may exist on the bigger islands, but they are nonexistent for the most part. Streams and creeks are the major water routes, especially in the mountainous regions. Gorges, valleys and ravines often become waterways during heavy rains.

South Island Group. The south island group consists of all the islands between the equator and 12° S, and between the eastern coast of Papua New Guinea and 165° E. Included in this group are the Bismarck Archipelago and the Solomons. Collectively, there are over 200 islands, islets and coral atolls. The majority of the islands are of volcanic origin. Some of the smaller islands are coral raised atolls. Information on some of the larger islands follows.

Manus Island. In the northwestern part of the region (near 2° S, 147° E), this island is 50 miles (80 km) long, 17 miles (27 km) wide, and has many smaller islands and coral reefs around it. A large harbor is located at the eastern end. The terrain is fairly rugged with a mountain range across the middle of the island. The range has several peaks with heights from 1,000 to 2,300 feet (300 to 700 meters); the highest peak lies in the southcentral part. Many small rivers and streams flow from the mountains to the coasts.

Mussau Island. This is the northernmost island in the group (near 1.5° S, 149.5° E). It is 20 miles (32 km) long and 10 miles (16 km) wide. A coral reef and a number of smaller islands are off its southern coast. The terrain is rugged and slopes upward towards a mountain top (elevation 2,133 feet/650 meters) in the east-central part of the island. There a few small rivers and streams that flow down from the mountain.

New Hanover. This island is near 2.5° S, 150.2° E. It is 34 miles (55 km) long and 22 miles (35 km) wide. The terrain is rugged as a mountain range covers the southeastern two-thirds of the island. There are several peaks with heights from 1,300 to 3,000 feet (400 to 900 meters). The highest peak is in the western end of the range.

New Britain. This crescent-shaped island is the largest of the south island group and marks the dividing line between the Bismarck and Solomon Seas. About 57 miles (92 km) from the northeastern coast of Papua New Guinea, New Britain is nearly 343 miles (552 km) long and 22 to 72 miles (35-116 km) wide. It also has a 30 mile (48 km) long peninsula that extends northward from near the center of the island. At the end of this peninsula, a horseshoe-shape lake surrounds one of several active volcanoes on the island. The island has five distinctive mountain ranges separated by valleys.

New Ireland. The south end of this long, narrow island is about 22 miles (35 km) east of New Britain. It stretches nearly 200 miles (322 km) northwestward towards New Hanover. The island is 4-30 miles (6-48 km) wide. Three mountain ranges are the predominate terrain features, with elevations up to 7,700 feet (2,300 meters). At the north end of the island, a fairly level plain extends about 13 miles (21 km) inland from Balgai Bay before it reaches the foothills of the mountains.

Bougainville Island. Bougainville is the largest of the Solomon Islands, approximately 127 miles (204 km) long and 49 miles (79 km) wide. It is 160 miles (257 km) east of New Britain. The terrain is very rugged as a mountain range almost extends the entire length of the island. The range hugs the eastern coastline and has several significant peaks with elevations from 4,700 to 8,900 feet (1,400- 2,700 meters). A coastal plain is on the southern end and along the western side of the mountain range. It extends inland between 4 and 10 miles (6-16 km) and has several marshes and swamps. The island has three small lakes. The first is in the center of the island northeast of Mount Bagana, while the other two are in the southern part of the island.

Choiseul Island. This island is nearly 85 miles (137 km) long and 4 to 20 miles (6-32 km) wide. It is about 32 miles (51 km) east-southeast of Bougainville Island. A mountain range occupies almost the entire western two-thirds of the island. There are several peaks between 1,500 and 3,300 feet (400-1000 meters). The highest peak is in the middle of the island. A coastal plain runs from the north end of the island southward along the east coast to the southern end.

New Georgia Group. This group consists of 6 large and more than a dozen small islands. It is about 40 miles (64 km) south of Choiseul Island and 60 miles (97 km) southeast of New Britain.

New Georgia. This L-shaped island is the largest of the group. It is about 50 miles (80 km) long and 25 miles (40 miles) across at its widest point, the northern end of the island. The remainder of the island is between 6 and 14 miles (10 - 23 km) wide. There are three mountain ranges separated by valleys. The northern range occupies about 50 percent of the northern part of the island. It is bordered by a coastal plain on its northeast through southwest sides and by a valley to the southeast. The highest point in the region is 2,821 feet (860 meters). The second range is in the middle of the island adjacent to the east coastline. It is bordered by valleys to the northwest and southeast and a coastal plain to the southwest. The highest point is 2,000 feet (610 meters). The third range is next to the southern coast and is bordered by a valley to the north and coastal plains to the west and east. The highest point is 2,695 feet (820 meters).

Vella Levella. This is the northernmost island in the group and is about 16 miles (26 km) long and 9-13 miles (14-21 km) wide. The northern half of the island is fairly hilly with elevations up to about 1,000 feet (300 meters). A valley lies to the south of these hills and is bordered on the other side by a small mountain range situated along the southern coast. The highest point is in the northern half of the range with an elevation of 3,000 feet (915 meters).

Kolombangara. This circular island, about 17 miles (27 km) in diameter, lies nearly midway between Vella Levella and the New Georgia islands. It has a rugged, mountainous interior topped by a volcano with an elevation of 5,800 feet (1,736 meters). A fairly level coastal plain surrounds the mountain.

Ganongga. This small island lies southwest of Vella Levella Island. It is about 13 miles (21 km) long and 4 miles (6 km) wide. The northern half of the island is fairly level while the southern half is hilly. The highest point of the island (2,850 feet/870 meters) is near the center.

Rendova. This boot-shaped island is off the southwest coast of New Georgia. It is about 14 miles (23 km) long and 8 miles (13 km) wide. A peninsula extends southeastward from the southern end of the island. There are two small mountain ranges separated by a valley. The first is adjacent to the southwestern coastline, the other is centered in the northern half of the island. The northern range has a high point of 3,477 feet (1,060 meters) while the southwestern range has a high point of 2,690 feet (820 meters).

Vangunu. Off the southeast coast of New Georgia Island, this island is approximately 15 miles (24 km) long and 12 miles (19 km) wide. It is generally mountainous except for a coastal plain along the northwestern coast. The highest point of the island is in the south, elevation 3,686 feet (1,125 meters).

Santa Isabel. This island lies 40 miles (64 km) east-southeast of Choiseul Island. It is approximately 140 miles (225 km) long and 15 miles (24 km) wide. A mountain range stretches nearly the entire length of the island. There is a narrow coastal plain on each side of it. The range has a number of peaks 1,800-3,900 feet (600-1,200 meters) tall. The highest peak is near the south end.

Malaita. This island is 50 miles (80 km) southeast of Santa Isabel. It is 100 miles (161 km) long and 7-19 miles (11-31 km) wide. The terrain is very rugged as the island is practically one long mountain range except for a narrow plain that runs halfway down the west coast. The island has several mountain peaks with elevations of 1,900-4,800 feet (600-1,500 meters). The tallest peak is near the center of the island.

Guadalcanal. This island is 100 miles (161 km) southeast of New Georgia. It is 92 miles (148 km) long and 33 miles (53 km) across at its widest point. Two-thirds of the island is mountainous along the southern coast. The northern third of the island is a coastal plain. There are numerous peaks with 3,500-7,648-foot (1,100-2,300 meter) elevations. The tallest peak is in the southern part of the island.

San Cristobal. Also known as Makira, this island is 38 miles (61 km) southeast of Guadalcanal. It is about 80 miles (130 km) long and 22 miles (35 km) wide at its greatest width. The island is generally mountainous except for a coastal plain at both ends of the islands and a valley about a third of the way down from the northwest end. There are several peaks with elevations of 2,200-4,200 feet (700-1,300 meters). The tallest peak is in the southcentral part of the island.

Rennell Island. This island, an uplifted atoll of coral limestone, is the southernmost in the south island group. About 120 miles (193 km) southwest of San Cristobal, it is approximately 50 miles (80 km) long and 2 to 9 miles (3-15 km) wide. The highest elevation is about 600 feet (200 meters), in the central part of the island east of a small bay.

Kiriwina Island. This western Solomon Sea island is 125 miles (201 km) from the southeastern coast of Papua New Guinea. It is about 25 miles (40 km) long and 3-6 miles (5-10 km) wide. It is fairly flat and low.

Muyua Island. Also known as Woodlark Island, this island is 145 miles (235 km) northeast of the eastern tip of Papua New Guinea. It is 38 miles (60 km) long and 12 miles (19 km) wide. Muyua is fairly flat except for a hilly area in the south-central part that leads to a shoe-shaped peninsula, which protrudes southward from the island. The highest point (1,175 feet/360 meters) is near the end of the peninsula.

Misima Island. About 140 miles (225 km) east of the eastern tip of Papua New Guinea, this small island is about 25 miles (40 km) long and 1 to 4 miles (2 - 6 km) wide. It has an east-west orientation. The terrain is very rugged as a small mountain range covers almost the entire island. A few peaks above 3,000 feet (900 meters) are present with the tallest peak (3406 feet/ 1038 meters) in the western half of the island.

Tagula Island. Also known as Sud-Est Island, it is 180 miles (290 km) east-southeast of the eastern tip of Papua New Guinea. The island is about 50 miles (80 km) long and 15 miles (24 km) wide at its widest point. The terrain is very rugged as the island is almost one big mountain range. The tallest peak, 2,621 feet/800 meters, is in the middle of the island.

Rossel Island. This island lies 22 miles (35 km) northeast of Tagula Island. It is 21 miles (34 km) long, 7 miles (11 km) wide, and has a v-shaped bay on the west end of the island. Rossel has a forested mountainous terrain. The highest point is in the eastern part of the island, at an elevation of 2,628 feet (801 meters).

Rivers and Drainage Systems. Small rivers, streams and creeks are the major water routes in the south island group, especially in the mountainous regions. Gorges, valleys and ravines often become waterways during heavy rains.

MAJOR CLIMATIC CONTROLS

Ocean Currents. The ocean currents play a significant role in maintaining the stability of the sea surface temperatures and the air temperatures of all Pacific islands. The major current is the north equatorial current (see Figure 2-3). It parallels the equator so the sun constantly heats the water as it moves westward into the region. This keeps the temperatures stable.

Asiatic High. This shallow, high-pressure cell dominates much of the Asian continent from late September to late April. The cold, dry outflow sets up the northeast monsoon. The outflow from this high also helps form the NETWC between December and May.

Australian High. This thermal high is present during the Southern Hemisphere winter (June to November). Its outflow helps drive the southwest monsoonal flow and strengthens the tradewinds. It also plays a role in the development of the tropical easterly jet (TEJ).

Australian Heat Low. This low develops during the Southern Hemisphere summer (December to May). It strengthens the northeast monsoon by increasing the pressure gradient between Asia and Australia. It disrupts the TEJ, which disappears, and pulls the NETWC southward.

Near Equatorial Trade Wind Convergence (NETWC). The NETWC is the dividing line between the southerly and northerly wind flows. It results from the convergence of the outflows from the northern and Southern Hemisphere subtropical highs. Although it stays south of the northern islands through most of the year, its changing positions help determine the wet and dry season for all the islands.

North Pacific High. This subtropical high initiates the North Pacific tradewinds that dominate the wind patterns throughout the year. The tradewinds meet with flow from other highs to form the NETWC. The position of this high is linked to NETWC movement and to oscillations in convection.

South Pacific High. This is the Southern Hemisphere counterpart to the North Pacific high. Outflow from the South Pacific high forms the South Pacific tradewinds. These southeasterly winds converge with the northeast tradewinds from the North Pacific high to form the NETWC. With the North Pacific high, its position helps dictate the NETWC's position.

South Indian Ocean (Mascarene) High. Outflow from this high helps form the Indian southwesterlies, a cross-equatorial flow that is one of the primary drivers of the southwest monsoonal flow. Its large east-west movement also causes seasonal variations in the strength of the equatorial westerlies.

South Pacific Convergence Zone (SPCZ). The SPCZ is a northwest-southeast oriented zone of cloudiness often observed on satellite imagery over the southwestern Pacific Ocean. It exists in the region of Australia and New Zealand and is considered to be a semipermanent feature. The SPCZ branches off the NETWC near Indonesia and extends southeastward across the southern Pacific. Formation results from the convergence of air flow from the South Pacific and the South Indian Ocean highs. It is reinforced by migratory high pressure systems that move eastward from Australia. The SPCZ shows little seasonal change in location or frequency of occurrence. Weather associated with the SPCZ includes moderate turbulence, frequent moderate or heavy rain, and thunderstorms with tops above 30,000 feet. Dense layers of altostratus to 20,000 feet or more are also common.

Southern Oscillation (El Niño, La Niña). This phenomena has a significant impact on rainfall. A drought is likely as a significant rainfall deficit sets up in an El Niño year and persists into mid- to late summer of the following year. During a La Niña, conditions are reversed. Excessive rains tend to occur late in a La Niña year and persist into the following summer.

Topography. Slight variations in the local distribution of rainfall are attributed to the random fall of the rain in showers. The more marked variations, however, are due to topography. Most of the islands are mountainous in character. The orographic effects on the prevailing winds are quite distinct in that the windward sides of the islands receive more rainfall than the leeward sides. The windward exposures on the upper slopes also receive more rain than lower slopes.

Tropical Cyclones. These synoptic-scale systems are a major threat to the region. Rarely a year goes by one does not affect some part of the Pacific. The high winds and heavy rains from these systems can cause considerable damage. The threat exists throughout the year, but is greatest during the latter part of the year.

General. A maritime tropical air mass dominates. The air mass is reinforced by the intense Asian winter circulation, although the islands are rarely affected by cold outbreaks. While the term "northeast monsoon" does not strictly apply to the central and especially the southern island groups, it is used to match the terms used in the other chapters of this regional study. The central and southern island groups are more affected by the tradewinds than by the monsoons.

North Island Group. The NETWC is well south of the area as the northeast tradewinds dominate the wind flow. Very weak, diffuse cold fronts occasionally pass over northern islands, and some shear lines move as far south as Guam. A tropical cyclone will occasionally form south of the northern islands and move towards the west and northwest. Though a tropical cyclone may form during any month, they are comparatively rare during the northeast monsoon.

Central Island Group. The NETWC lies south of the equator as the northeast tradewinds dominate. A tropical cyclone will occasionally form in the region and move towards the west and northwest. Tropical cyclone activity is greatest during the northeast monsoon since the NETWC is located south of the equator.

South Island Group. The NETWC is located over or just to the south of the area. A north to northwesterly flow dominates the low-level environment. The air masses that move into the region originate in the North Pacific high. The low-level air stream is warm, strong, and deep. The air is moist at its source and receives additional heating and moisture on its journey. About 95 percent of tropical cyclone activity is this region occurs during this season because the NETWC is south of the equator and provides a catalyst for cyclogenesis. These systems are still developing and generally do not undergo significant intensification until they move out of the area. They still dump tremendous amounts of rain on the islands they pass.

Sky Cover. Terrain plays a major role in cloudiness. The warm, very moist and unstable equatorial air mass interacts with the mountains. Cloudiness becomes widespread along the windward sides, and the tops of the mountains are often obscured above the lifted condensation level (LCL). It often reaches its maximum during the afternoon. The clouds are generally convective in nature. The clouds tend to spread out and dissipate after dark, unless a steady wind maintains the clouds on the ridge tops and windward slopes. After midnight, thin stratus tends to form over swampy valleys and upland basins. The stratus layers dissipate by mid- to late-morning in most cases.

North Island Group. Cloudiness is widespread. Clear skies are not common; they occur under 4 percent of the time over the northern islands and rarely over the southern islands. Ceilings are observed 35-48 percent of the time in the north, and 45-68 percent of the time in the south. Ceilings below 3,000 feet occur less than 20 percent of the time (see Figure 7-3). Many higher peaks on the northern islands are cloaked by clouds above the lifted condensation level (LCL) when these lower ceilings occur. Cumuliform clouds predominate, but vertical extent is limited by the tradewind inversion. Clouds that do develop vertically have tops that lean or are sheared off near the inversion level.

Central Island Group. Cloudiness is widespread; clear skies are rare. Ceilings occur 75-85 percent of the time in the west and over 90 percent of the time in the east. Ceilings below 3,000 feet occur less than 20 percent of the time in the northern parts of the region and nearly 50 percent of the time in the south and east. Low ceilings occur most during the day, generally with precipitation. A few larger islands, like Pohnpei, may have more cloudiness occurrences due to topographical influences. The mountain slopes on the windward sides of these islands are often covered by clouds above the LCL. Others, like Nukuoro Atoll are close enough to the equator to be affected by the clouds with the NETWC. Islands with significant tropical rain forests get morning stratus. Cumuli, limited by the tradewind inversion, predominate.

South Island Group. Cloudy skies dominate; clear skies are rare. Ceilings occur 80-85 percent of the time over the northern islands and 65-75 percent of the time over the central and southern islands. Ceilings below 3,000 feet generally occur under 30 percent of the time (see Figure 7-3), normally with precipitation. The NETWC is responsible for much of the cloudiness. When the NETWC is very active, the width of the area of cloudiness varies from 50 to 200 miles (80-320 km). A high canopy of cirrostratus, up to 300 miles (480 km) wide, lowers to irregular layers of altostratus. The altostratus then abruptly yields to a wall of cumulonimbus clouds with tops to 30,000 feet. When the NETWC is weak, the cloud cover is scattered altostratus or altocumulus at 7,000-14,000 feet and scattered towering cumulus with tops to 12,000 feet. A few cumulonimbus are also present.

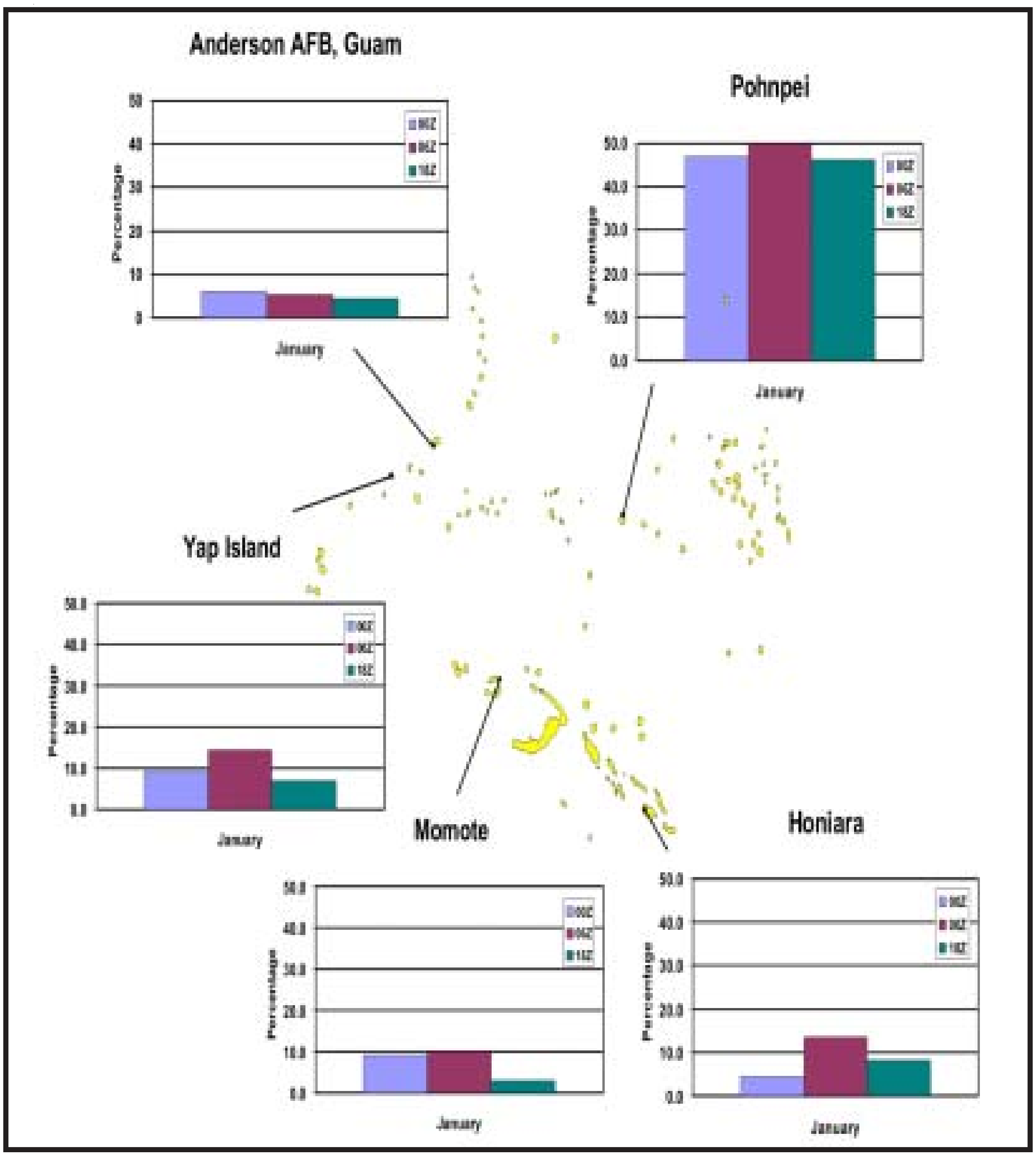

Figure 7-3. Northeast Monsoon Season Percent Frequency of Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet, based on location and diurnal influences.

Visibility. Visibility is generally good, usually better then 7 miles (11,000 meters). See Figure 7-4. The visibility falls below 3 miles (4,800 meters) less than five percent of the time. Rain limits visibility, usually in showers. A severe downpour may reduce visibility to less than a half mile (800 meters) for a short time. Poor visibility of longer duration almost always accompanies tropical cyclone passages. Fog, haze, and blowing dust also contribute to reduced visibilities, but occur rarely. Ground fog is more common over swampy areas and river valleys on cool, fair weather mornings and usually dissipates by mid-morning. Cloud fog occurs quite frequently at the 2,000-3,000 foot (600-900 meter) level on the windward mountain slopes when extensive cloud banks are present. It develops by mid- to late afternoon and persists until the cloud banks dissipate after sunset.

Haze poses a problem in the southern island group. Within that group, it occurs about 10-20 percent of the time in the north, 15-35 percent in the central area, and up to 50 percent of the time in the south. Dust and smoke from Australia is partly responsible. Salt particles picked up by the tradewinds also contribute. Visibility generally remains above 11,000 meters though it can fall to 5-6 miles (8,000-9,000 meters). Visibility occasionally drops to 4,800 meters, but only during extended dry periods or calm wind conditions, especially on the windward sides of mountain ranges. The haze disappears after a heavy rain.

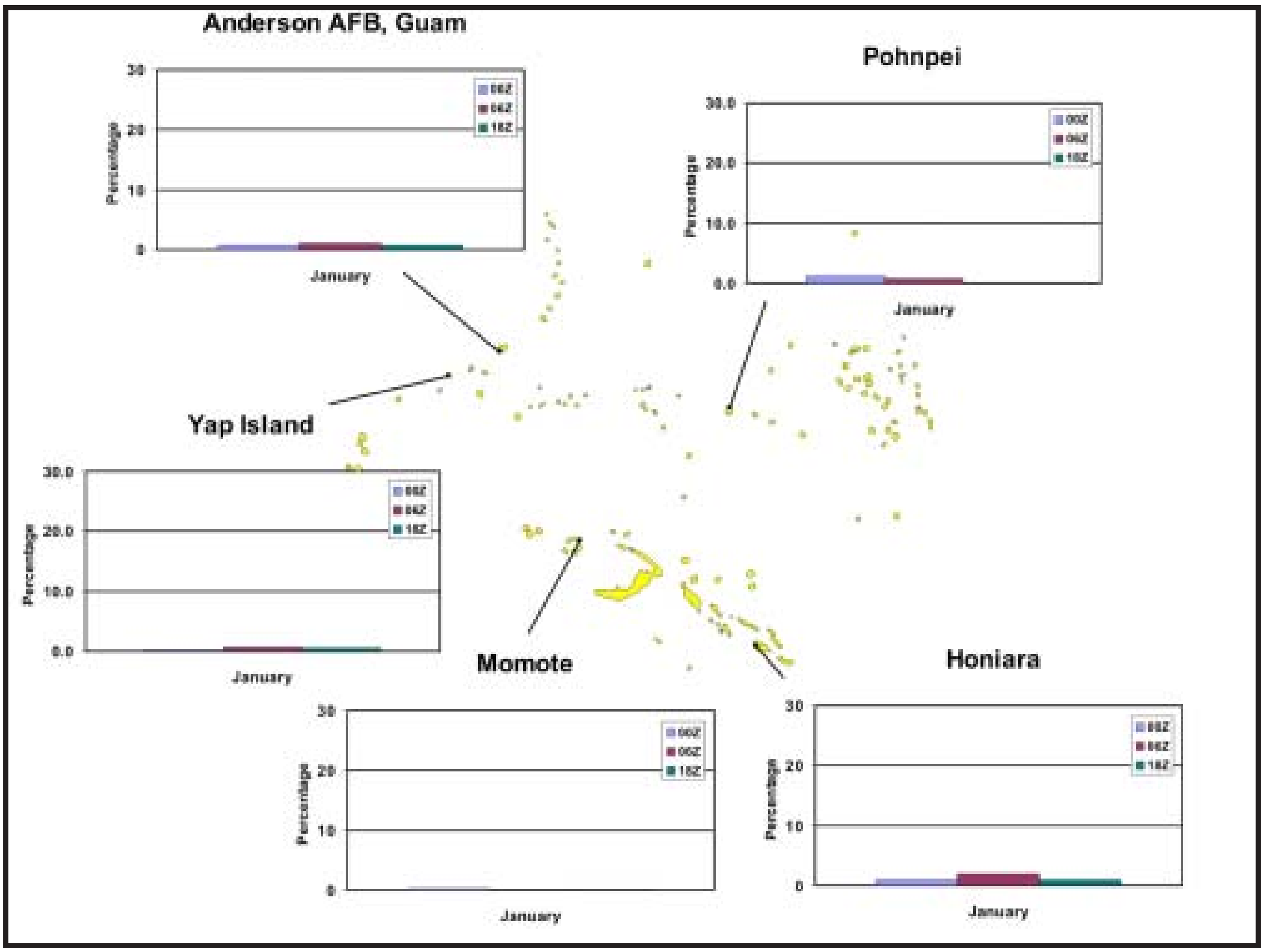

Figure 7-4. Northeast Monsoon Season Percent Frequency of Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percent of visibility below 4,800 meters, based on location and diurnal influences.

Surface Winds. Larger islands have pronounced land/sea breeze regimes that reach up to 2-3 miles (3-5 km) out to sea. See Figure 7-5. The sea breeze usually sets up by 0900-1000L. It is strongest between 1400-1500L, where it can be 1,500-2,000 feet deep. The sea breeze dies after 1800L. A land breeze then sets up and persists through the nighttime hours. Foehns occur on larger islands with mountain ranges. These warm, dry winds flow down the leeward sides due to the overflow of the prevailing winds against the windward sides. They bring warmer temperatures, lower humidity, and clear skies to the lee sides of the islands.

North Island Group. The northeast tradewinds dominate. The winds are from the east through northeast at 7-12 knots. The northern islands may have westerly winds behind a cold front. Wind gusts of 130 knots have been reported with a typhoon.

Central Island Group. The winds are dominated by the northeast trades. They are strongest in December-April. The winds blow from the east through northeast at 5-14 knots. The higher speeds occur in the eastern part of the area. Places in the southern part of the area may get south winds if the NETWC moves north of them. Maximum wind gusts to 96 knots have been reported in the northern half of the region, usually with tropical cyclones. In southern and far western areas, where tropical cyclones are not as common, maximum gusts of 30-40 knots occur with convective activity.

South Island Group. North to northwest winds dominate. Speeds over the water are fairly constant, about 8-12 knots. Both speed and direction over land depend on topography; inland, there is endless variety. The prevailing wind directions of coastal locations, however, tend to match the prevailing winds for the region. Mean speeds are 3-10 knots. Maximum wind speeds are 43-53 knots in the north and central areas and 58-80 knots in the south. Thunderstorms and squalls cause most high gusts. Squalls generally blow with the prevailing winds and last 5-15 minutes. Tropical cyclones cause the highest wind gusts. These range from under 20 percent of the time over the northwestern and southwestern islands to 35-65 percent of the time over the central and southern islands. The area lies in the doldrums, a zone of calms or light, variable breezes.

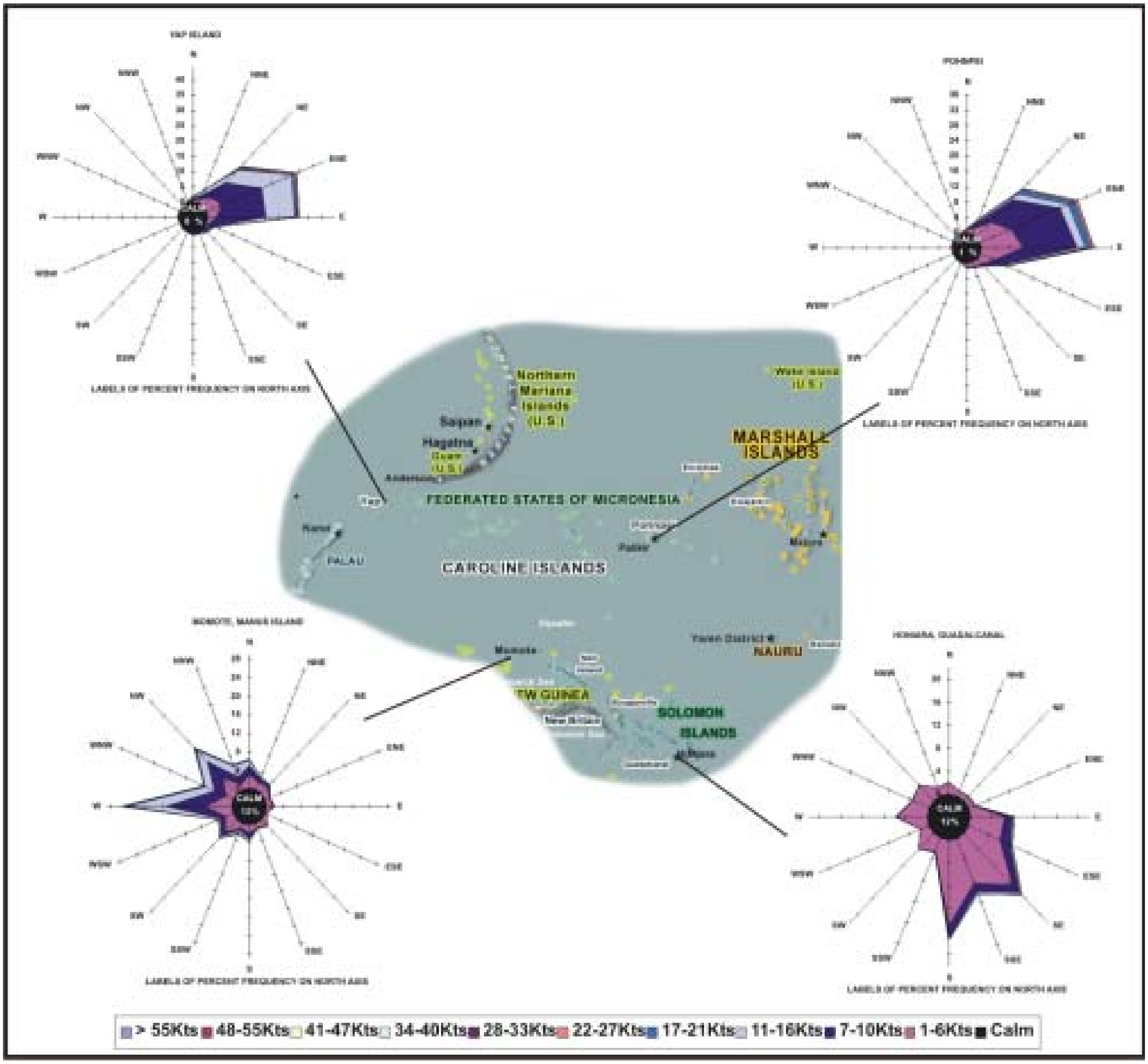

Figure 7-5. January Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds, based on frequency and location.

Upper-Air Winds. Figure 7-6 depicts wind roses for selected locations.

North Island Group. Sustained easterlies prevail from the surface to 20,000 feet. Speeds average 9-12 knots at the surface and increase to 15-22 knots between 3,000 and 7,000 feet. The winds diminish above 7,000 feet and average 12-17 knots through 20,000 feet. Winds above that average 12-15 knots. Wind directions above 20,000 feet are highly variable and depend on the position of the subtropical ridge. From December to May, the ridge axis lies over the Mariana Islands.

Central Island Group. Deep, sustained easterly winds prevail. The winds are strongest in January and February when the subtropical ridge is at its southernmost position. Wind speeds average 5-15 knots at the surface and increase to 15-20 knots between 4,000 and 7,000 feet. The winds diminish above 7,000 feet and average 10-15 knots through 15,000 feet. Winds above this level average 25-35 knots through 40,000 feet. As the subtropical ridge moves northward in March, the winds diminish. The wind speeds average 10-15 knots through 40,000 feet by May.

South Island Group. A west to northwesterly wind flow dominates through 10,000-15,000 feet. Speeds average 6-14 knots over the region. The strongest winds are over the northern islands and the weakest are over the southern islands. The winds above 15,000 feet are generally from the east. Wind speeds between 15,000 and 30,000 feet average 10-16 knots and are strongest in February.

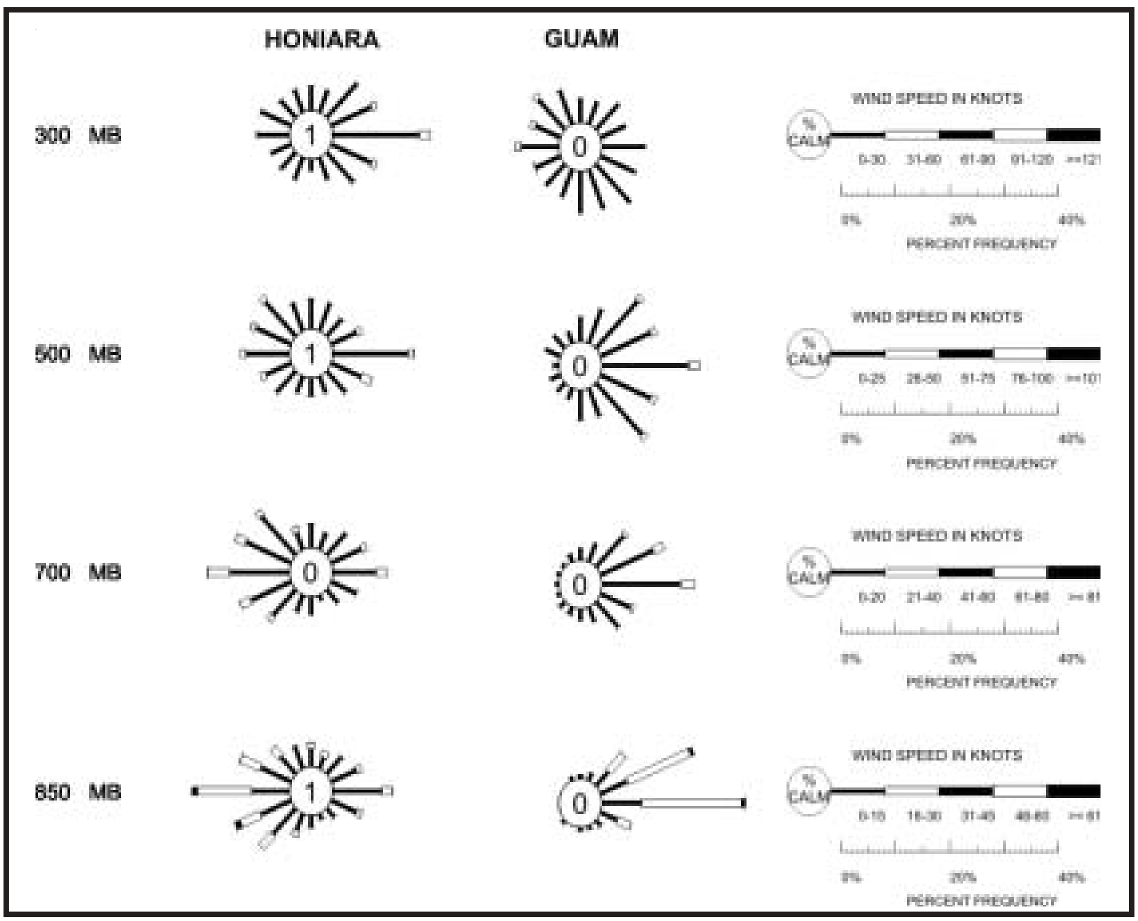

Figure 7-6. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 mb and 300 mb over .

Precipitation. Many of the islands in the region have mountainous terrain, so the amount of rainfall any particular location gets depends upon the surrounding topography. See Figures 7-7 and 7-8. Locations on the windward side of the mountains will receive more rain than locations on the leeward side. Also, locations on the end of peninsulas away from the mountains, and exposed to the prevailing wind flow, have less rainfall than locations closer to the mountains. The orographic lifting responsible for the heavier rainfall totals along the mountains is absent.

North Island Group. Although the Marianas experience 15-21 days of rain a month, they get less than 30 percent of the annual rainfall in this season. The mean monthly rains are 2-5 inches (50-125 mm). Extreme minimums of under 1 inch (25 mm) have occurred in most months. Heavy rains are also possible as monthly rainfall totals have exceeded 30 inches (750 mm) at some sites. Heavy rains are usually associated with tropical cyclones. Precipitation usually falls as intermittent light rainshowers. Thunderstorm activity is rare. On average, less than 1 thunderstorm day occurs per month. When thunderstorms occur, they give rise to local squalls characterized by brief, heavy showers.

Central Island Group. The islands average 16-22 days of rainfall each month. Some islands have rain as few as 11 days per month, while others have rain almost every day . The mean monthly rainfall totals range from 2 inches to just over 23 inches (50 mm-575 mm) per month. February is driest and May is wettest for most locations. The islands in the northern parts of the area have the least rain, and the amounts increase southward. This distribution reflects the position of the NETWC, which usually remains south of the equator during the northeast monsoon. Some of the higher amounts of rainfall are caused by topography. Pohnpei, which has one of the greatest rainfall totals for the region, has its reporting site on the north side of the island in a basin valley near the ocean. The valley is encircled on three sides by a mountain ridge and the mouth of the valley faces the northeast. Since the island is affected by the northeast tradewinds throughout the season, the moist air flow interacts with the ridge above the station and orographic lifting is responsible for the heavy rainfall totals.

The region is susceptible to drought conditions, especially in an El Niño year. Monthly rainfall totals as low as 0.20 inches (5 mm) have been reported. Even Pohnpei, one of the rainiest islands, is affected. The island, which averages 10-20 inches (250-500 mm) of rain per month during the northeast monsoon, has reported a monthly total as low as 1.10 inches (28 mm). Heavy rainfalls are also possible as monthly totals have exceeded 40 inches (1,000 mm) at some locations. These heavy rains are usually associated with a tropical cyclone or an extremely active NETWC. Thunderstorm activity is not very common during the northeast monsoon. For most of the islands and atolls, less than one thunderstorm day occurs per month. The strong tradewind inversion keeps convective activity in check. When thunderstorms occur, they give rise to squalls characterized by brief, heavy showers.

South Island Group. The NETWC and the interaction of the unstable, equatorial air with terrain are responsible for much of the high rainfall activity this season. The islands average 19-22 days of rain per month. Some sites have rain as few as 9 days per month, while others see rain as many as 27 days per month. Mean monthly rainfall totals range from 5 to just over 15 inches (127-380 mm). December is the driest month and March is the wettest. High totals are also possible as monthly and twenty-four hour rainfalls have exceeded 35 inches (900 mm) and 12 inches (300 mm) respectively at some sites. These heavy rains are usually associated with an extremely active NETWC or a tropical cyclone. Auki, Malaita Island and Kira Kira, San Cristobal both get a lot of rainfall due to their proximity to mountains. They have two of the highest rainfall totals for the region.

Thunderstorm activity is quite common. The area averages 5-7 thunderstorm days a month. Most of the activity takes place in the central and southern islands where a few places see 10-12 thunderstorm days a month. Thunderstorms can occur at any time of the day, but the favored times are in the heat of the day (14L-16L) and in late evening to overnight hours (21L-05L). Tops over 50,000 feet have been reported. Many thunderstorms at Rabaul, New Britain, Munda, New Georgia and Honiara, Guadalcanal are formed by orographic lifting. Taro Island, southeast of Bougainville Island, is where reconvergent flow often comes together. The island averages 7 to 11 thunderstorm days a month as a result.

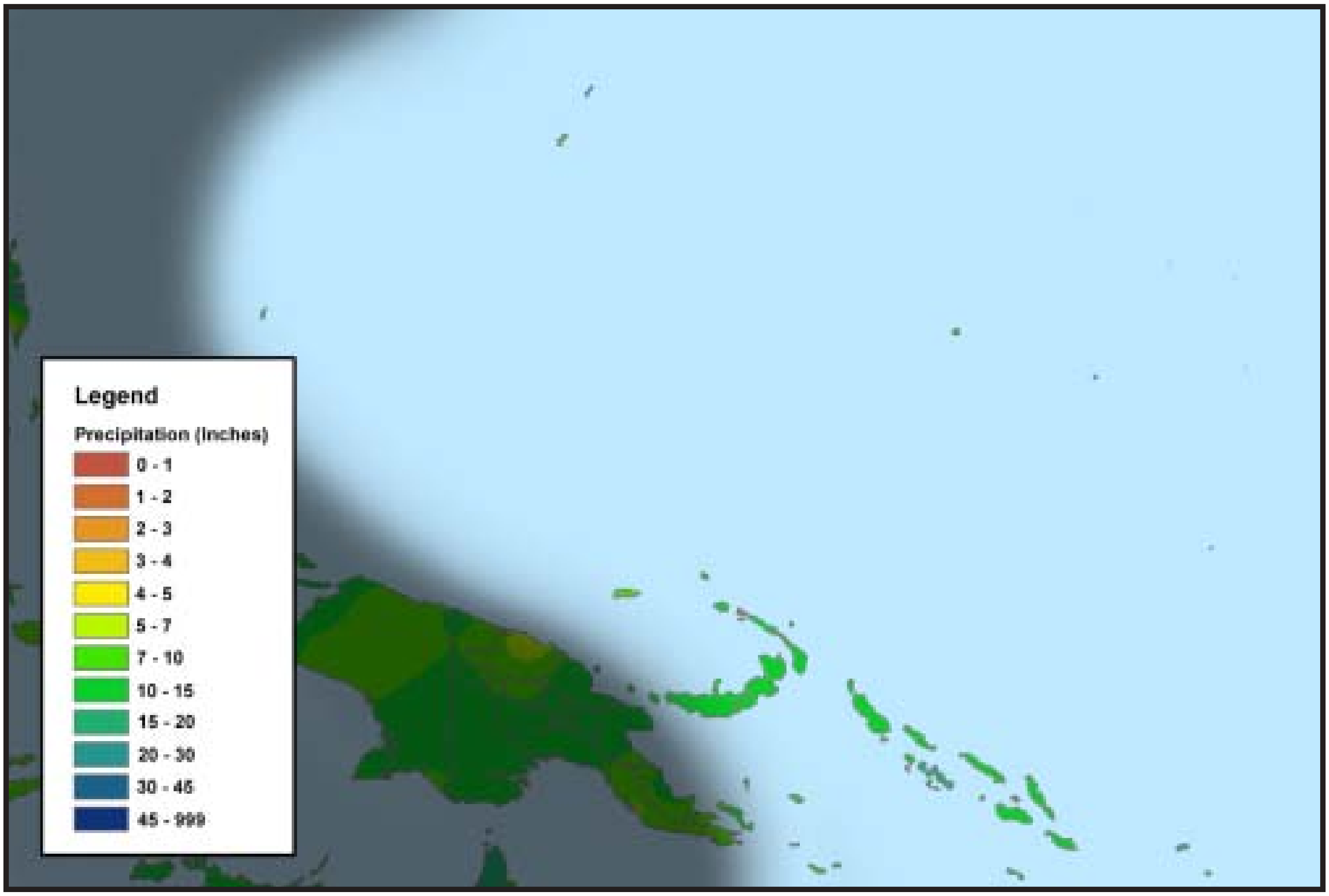

Figure 7-7. January Mean Precipitation. The figure shows mean precipitation in the region.

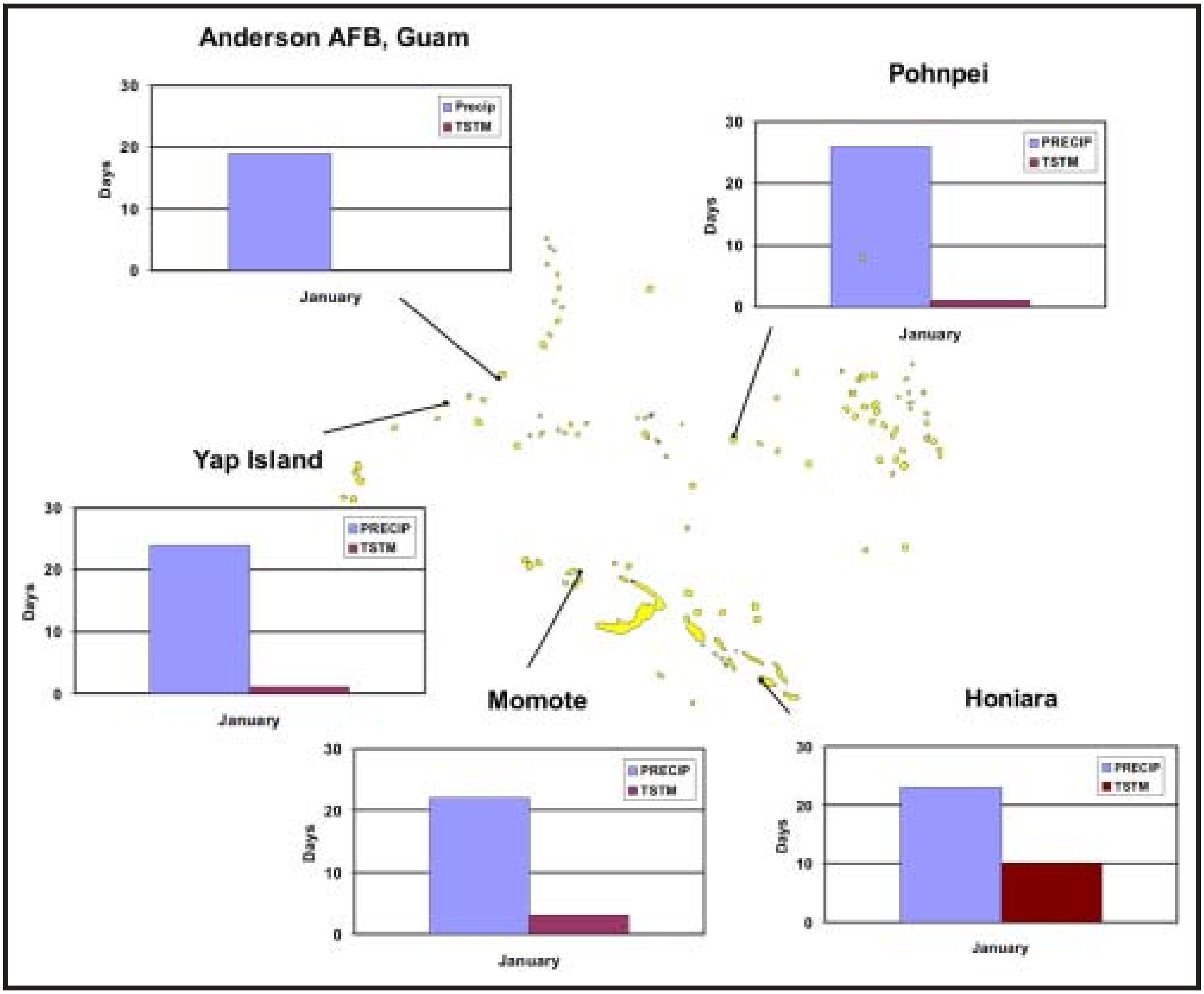

Figure 7-8. Northeast Monsoon Season Mean Rain and Thunderstorm Days. The graphs show the average seasonal occurrences of rain and thunderstorm days for representative locations in the region.

Temperatures. See Figure 7-9 and 7-10.

North Island Group. Mean high temperatures range from 82° to 88°F (28° to 31°C), the mean lows from 73° to 77°F (23° to 25°C). The record high was 98°F (37°C), and the record low was 65°F (18°C).

Central Island Group. The temperatures are stable through the season. Mean highs range from 82° to 88°F (28° to 31°C), the mean lows from 73° to 82°F (23° to 28°C). The extreme high and low were 103° and 64°F (39° and 18°C).

South Island Group. The temperatures are stable through the season. Mean highs range from 84° to 88°F (29° to 31°C), the mean lows range from 73° to 82°F (23° to 28°C). The extreme high and low were 112° and 63°F (44° and 17°C).

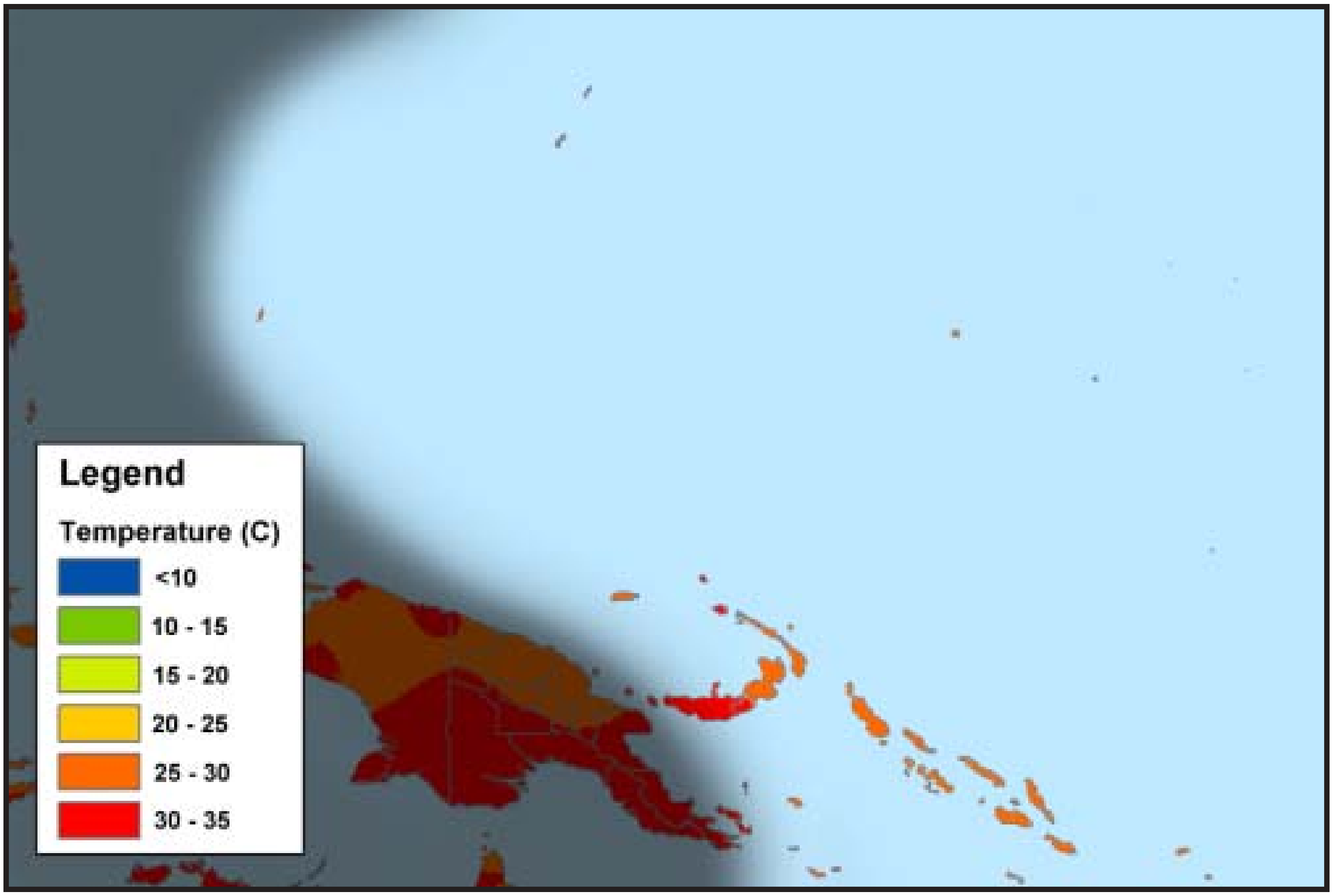

Figure 7-9. January Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the coldest month of the northeast monsoon season. Daily high temperatures are often higher than the mean.

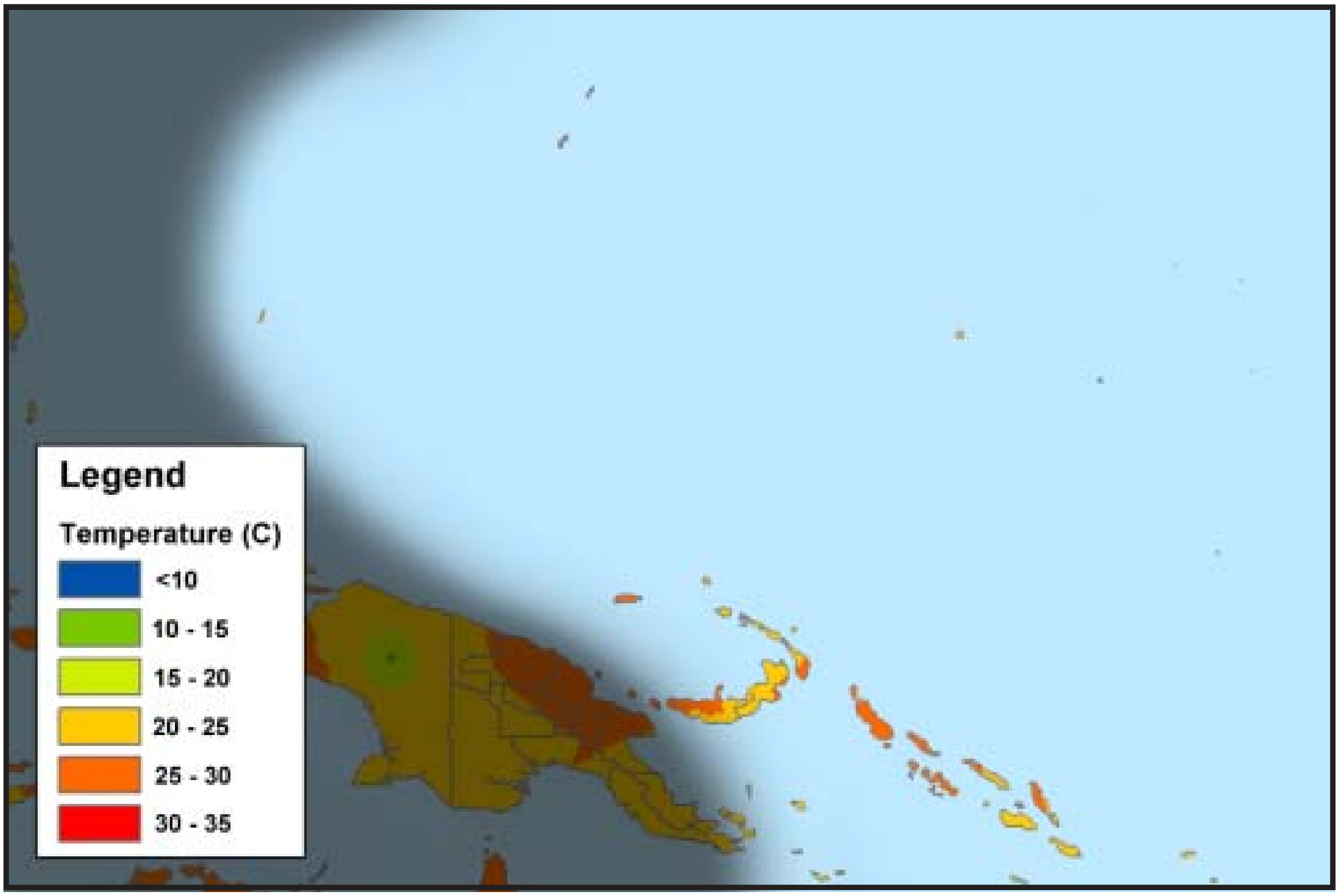

Figure 7-10. January Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the coldest month of the northeast monsoon season. Daily low temperatures are often lower than the mean.

General. While the term "southwest monsoon" does not strictly apply to the central and especially the southern island groups, it is used to match the terms used in the other chapters of this regional study. The central and southern island groups are more affected by the tradewinds than by the monsoons.

Maritime tropical air dominates. The North Pacific high moves north and west, the Asiatic high disappears, and the subtropical ridge migrates northward. The southeasterly tradewinds from the South Pacific high and the Indian southwesterlies cross the equator to bring very humid, unstable equatorial air into the region. Most tropical cyclones form in an area between 5° N to 20° N and 130° E to 155° E. Movement is generally towards the west-northwest. Some recurve to the north and northeast. The tropical cyclone season is in full swing.

North Island Group. The NETWC moves north and remains near the Marianas between July and September before it retreats southward. During this time, it may move over some, if not all, of the islands. The northeast trades continue to influence the wind flow, but are weakened without the Asiatic high to reinforce them. Many tropical cyclones that form near the Marianas do not fully develop until after they move west of the islands, but they can still dump tremendous amounts of rain. Storms that develop further east, and thus have more time to develop and inflict severe damage on the islands.

Central Island Group. The NETWC migrates north to over the northern part of the region (between July and September) before it retreats southward. A southwesterly wind dominates the western part of the region while the northeast tradewinds continue to influence the eastern part. Although the tropical cyclone season is in full swing, the threat to the central island group is less as the prime formation areas and major typhoon tracks have shifted north. Any storm that forms in the region usually remains at or below tropical storm strength until it moves north of 10° N. These storms, however, still dump tremendous amounts of rain.

South Island Group. The NETWC lies north of the equator, however, its movement is erratic and could affect the northern islands in the May/June and October/November time periods. A steady, southeasterly wind flow dominates the low-level environment. The air masses that move into the region originate in the subtropical belt of high pressure between 23°S and 35°S. This high pressure belt is stronger and lies much farther north in this season. The air mass is relatively cool and stable at its source. The relative humidity is low and a tradewind inversion exists below 10,000 feet. As the air mass moves over the warm, equatorial Pacific, it warms and becomes more humid. When the air mass finally reaches the region, it is very moist to 6,000-8,000 feet, where a temperature inversion is found. The air mass is relatively dry above the inversion. Except for the southeast parts of the area in May and November, tropical cyclone activity is almost nonexistent in this season. Those that do form are very weak and generally do not intensify until they leave the area.

Sky Cover. Terrain plays a major role in cloudiness. The warm, moist, low-level air from the southeast interacts with the mountains. When the air is lifted over the mountains, cloudiness becomes widespread along the windward sides, and the tops of the mountains are often obscured above the LCL. It often reaches its maximum during the afternoon. The clouds are generally convective in nature with heavy rainfall. The clouds tend to spread out and dissipate after dark, unless a steady wind maintains the clouds on the ridge tops and windward slopes. After midnight, thin stratus tends to form over swampy valleys and upland basins. The stratus layers dissipate by mid- to late-morning in most cases.

North Island Group. Mean cloudiness reaches its maximum; clear skies are rare. Ceilings at all levels are observed 60 percent of the time in the north and 65-70 percent of the time in the south. Ceilings below 3,000 feet occur under 20 percent of the time (see Figure 7-11) over the northern islands and less than 10 percent of the time over the southern islands. Ceilings below 1,000 feet rarely occur anywhere. Many of the higher peaks on the northern islands may be cloaked by clouds when these lower ceilings occur. Low ceilings are usually associated with precipitation. The weakening of the northeast trades allow for an increase in convergence. This disrupts the tradewind inversion and intensifies convective activity. Cumulus congestus and cumulonimbus clouds form in the afternoons.

Central Island Group. The cloudiness reaches its maximum and clear skies continue to be rare. Ceilings occur 80-90 percent of the time in the west, and nearly 95 percent of the time in the east. Ceilings below 3,000 feet usually occur under 30 percent of the time (see Figure 7-11) in the northern and western parts of the region, and increase to nearly 50 percent in the south and east. Low ceilings are generally associated with precipitation. Some of the larger islands, like Pohnpei, have more cloudiness due, in part, to topographical influences. The mountain slopes on the windward sides of these islands are often covered by clouds above the LCL. Islands with significant tropical rain forest coverage have stratus in the mornings. Cumulus clouds are the predominate cloud types. High clouds, such as cirrus or cirrostratus are often present but are obscured by lower clouds. Clouds at middle heights occur quite frequently, especially if there is a tropical disturbance in the area. The amount of convective activity increases during the southwest monsoon. The weakening of the northeast tradewinds allow increased convergence to take place and disrupt the tradewind inversion. Cumulus congestus and cumulonimbus clouds form in the afternoons.

South Island Group. Cloudy skies continue to dominate, but the overall amount of cloudiness is lower in this season. Clear skies are still rare. The occurrence

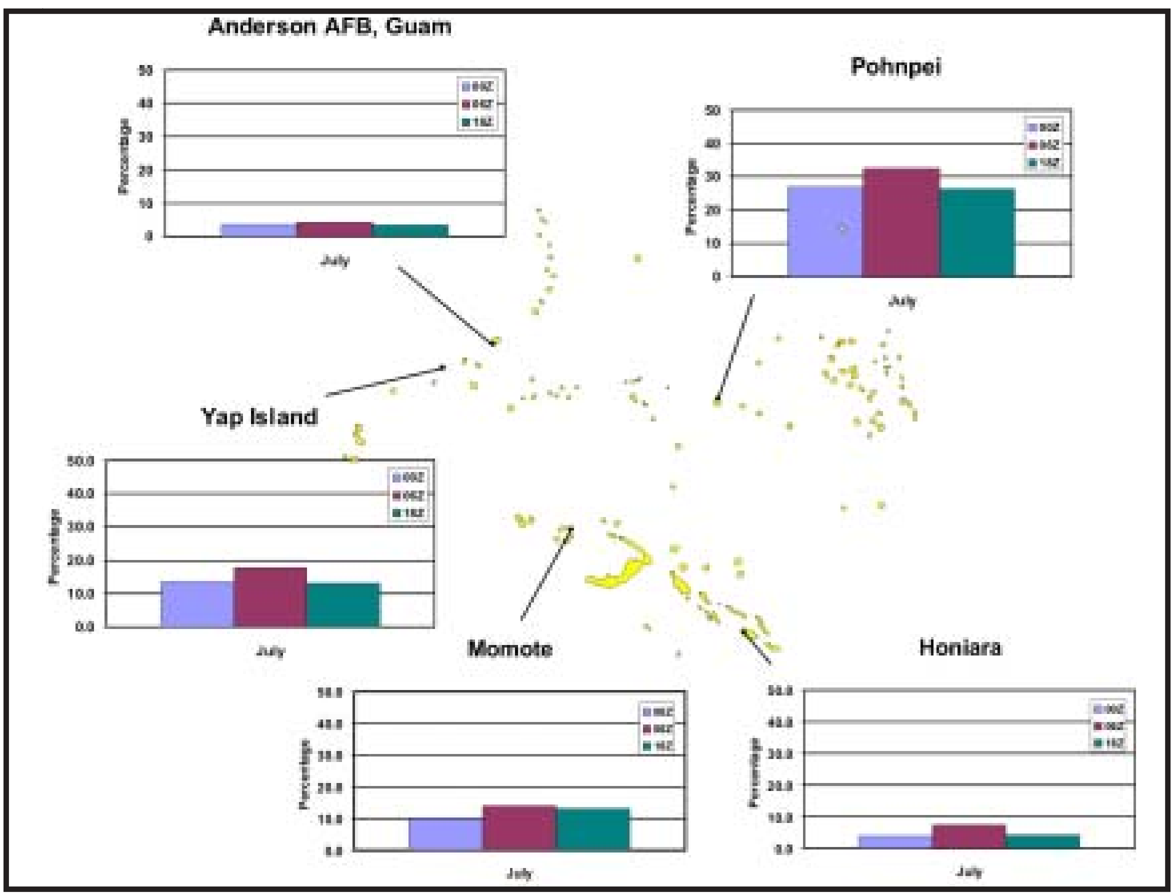

Figure 7-11. Southwest Monsoon Season Percent Frequency of Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percent of ceilings below 3,000 feet, based on location and diurnal influences.

of ceilings is lower. They occur 70-75 percent of the time on the northern and central islands and 60-70 percent of the time on the southern islands. Ceilings below 3,000 feet occur less often this season except for the southwestern portion of the region. They occur less than 20 percent of the time over most of the region and about 30-35 percent of the time over the southwestern portion (see Figure 7-11). The lower ceilings are normally associated with precipitation events. The SPCZ accounts for much of the cloudiness. When the SPCZ is active, the weather includes cumulonimbus clouds with tops above 30,000 feet and dense layers of altostratus to 20,000 feet. When it is not active, the clouds are scattered to broken tradewind cumulus with isolated showers and thunderstorms.

Visibility. Visibility continues to be generally good and falls below 3 miles (4,800 meters) less than 5 percent of the time anywhere (see Figure 7-12). The primary factor that limits visibility is rain, which usually comes in the form of showers. A severe downpour may occasionally reduce visibility to less than a half mile (800 meters) but only for a short time. Poor visibility of longer duration is usually associated with tropical cyclone passages. Fog, haze, and blowing dust also contribute to reduced visibility, but these phenomenon occur rarely.

Ground fog is more common as it occurs over swampy areas and river valleys on cool, fair weather mornings. It usually dissipates by mid-morning. Cloud fog occurs quite frequently at the 2,000-3,000 foot (600-900 meter) level on the windward side of the mountains when extensive cloud banks are present. It develops by mid-to-late afternoon and persists until the cloud banks begin to dissipate once the sun goes down.

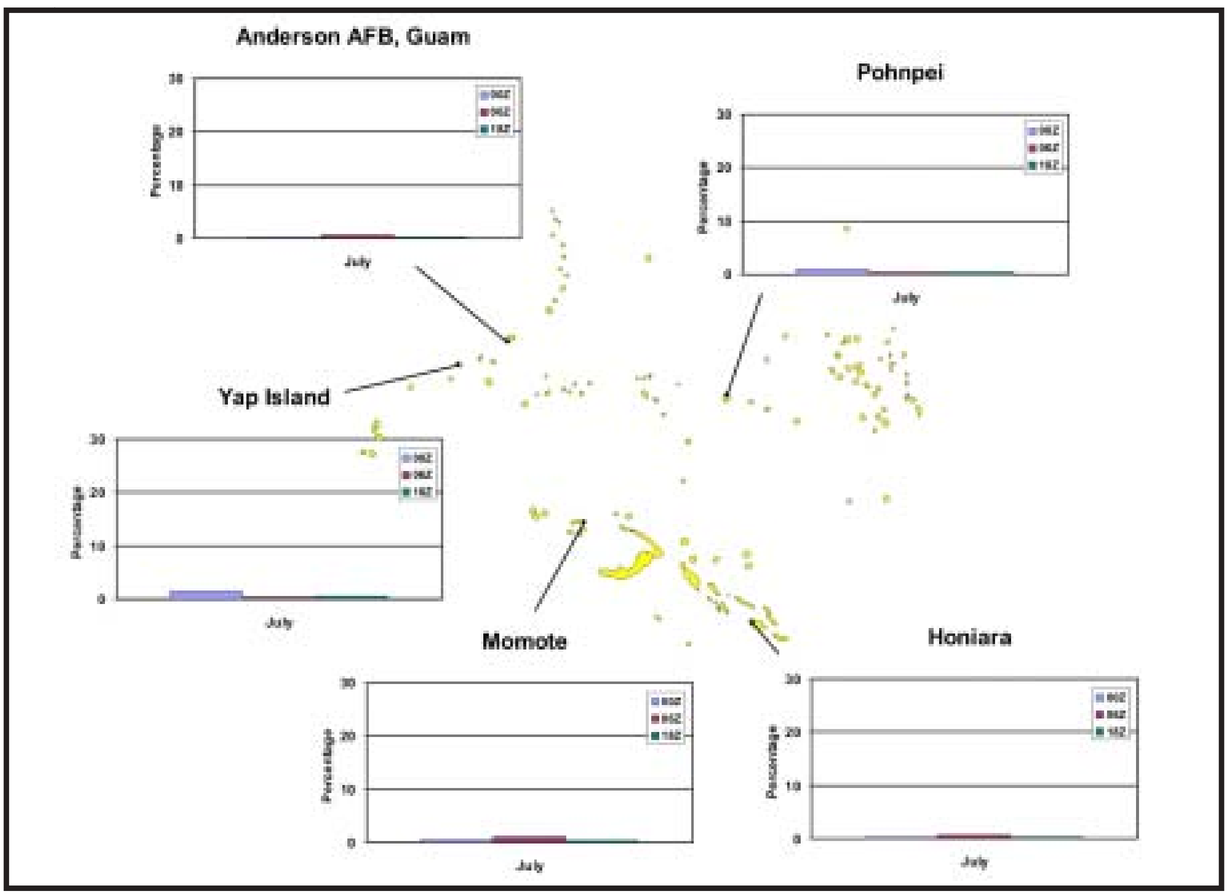

Figure 7-12. Southwest Monsoon Season Percent Frequency of Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percent of visibility below 4,800 meters, based on location and diurnal influences.

Haze continues to pose a problem. It occurs about 5-25 percent of the time over the northern islands, 15-35 percent over the central islands, and up to 60 percent of the time over the southern islands. Dust and smoke from Australia are responsible for some of the haze problem. Salt particles picked up by the tradewinds also contribute to the problem. Visibility generally remains above 7 miles (11,000 meters) but can fall to 5 miles (8,000 meters). The visibility will occasionally deteriorate to 3 miles (4,800 meters) but only during extended dry periods or under calm wind conditions, especially on the windward sides of mountain ranges. The haze generally disappears after a heavy rain.

Surface Winds. Wind speeds and directions over land depend on the topography. Inland, there is an endless variety (see figure 7-13). The prevailing wind directions of coastal locations, however, generally match the prevailing wind direction for the area. A land/sea breeze regime exists on larger islands and can reach 2-3 miles (3-5 km) out to sea. The sea breeze usually sets up by 0900-1000L. It is strongest between 1400-1500L, when it can be 1,500-2,000 feet deep, and dies after 1800L. A land breeze then sets up and persists through the nighttime hours. Foehn winds occur on the larger islands with mountain ranges. These warm, dry winds result in warmer temperatures, lower humidity, and clear skies on the leeward sides of the islands.

North Island Group. The northeast tradewinds continue to dominate, but they are not as strong as during the northeast monsoon. The wind is from the east to southeast at 5-9 knots. South to southwesterly winds occur when the NETWC moves over the islands. Typhoon wind gusts up to 130 knots have been reported.

Central Island Group. The prevailing wind direction during the southwest monsoon is dependent on the NETWC. If the NETWC is south and/or west of a location, the prevailing wind direction is determined by the northeast tradewinds. If the NETWC is north and/or east, the wind direction will be determined by either the Indian southwesterlies or the southeast trades. The Indian southwesterlies will have its greatest influence in the western part of the area while the southeast trades will have their greatest impact in the east. Mean wind speeds are 3-12 knots with the higher speeds in the eastern half of the area. Gusts to 95 knots occurred in the northern half of the area with tropical cyclone activity. In the southern or far western part of the region, maximum wind gusts of 40-45 knots have occurred with very weak tropical cyclones or squalls.

South Island Group. An east-to-southeast wind flow dominates the region. The wind speeds over the water are fairly constant, 10-15 knots. Wind speeds and directions inland vary widely and depend on terrain. Coastal prevailing winds, however, generally mirror the prevailing wind direction for the area . Mean speeds are 4-11 knots. Maximum speeds are 35-80 knots on the northern and central islands and 40-80 knots on the southern islands. Thunderstorms and squalls are generally responsible for high gusts as tropical cyclone activity is rare during this season. Squalls are the most common source and occur most often on the windward coasts and slopes. Gusts to 50-60 knots are likely, with higher gusts possible. The squalls generally blow with the prevailing winds and last 5 to 15 minutes.

A fairly high rate of calm winds continues although the percentages are down from the northwest tradewind season. Calms occur under 20 percent of the time on the northwest and southwest islands, 20-40 percent of the time on the central islands, and 40-55 percent of the time on the southern islands. The area is in the doldrums. The terrain is also a factor as locations on the leeward sides of the islands will have a greater percentage of calm winds than those on the windward sides.

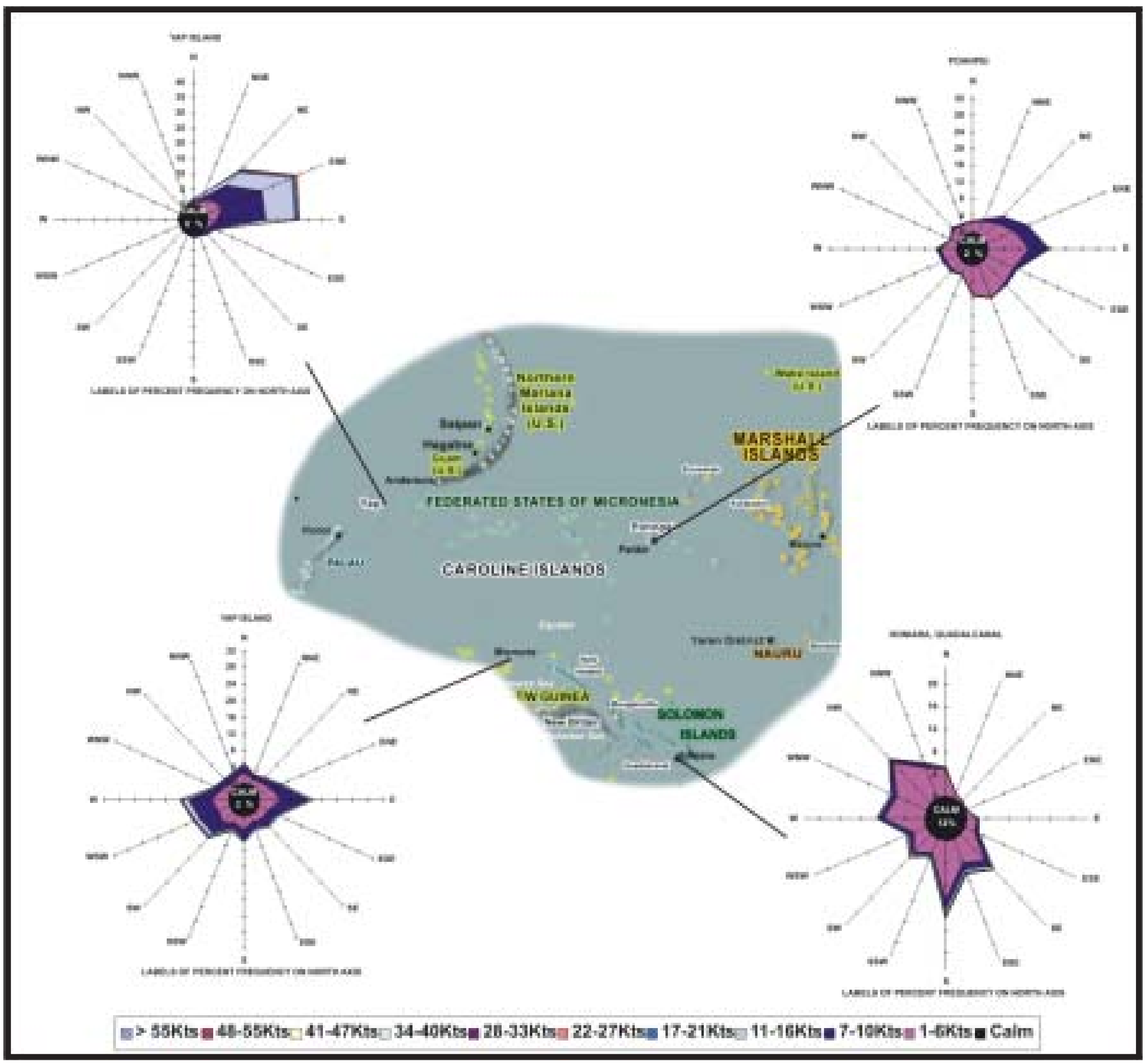

Figure 7-13. July Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds, based on frequency and location.

Upper-Air Winds. See Figure 7-14.

North Island Group. East winds dominate to over 20,000 feet. Wind speeds are fairly uniform through the atmosphere; they average 8-10 knots at the surface and 12-15 knots above 1,000 feet. There is more variability in the wind directions below the 300-mb level than is seen during the northeast monsoon. Movement of the NETWC over and north of the islands will make low-level winds more southwesterly. The wind directions above 20,000 feet still depend on the position of the subtropical ridge, which usually lies north of the Mariana Islands.

Central Island Group. The southwest monsoon is strongest over the western section. The tradewinds still have the greatest influence over the eastern section, though the southwesterly wind flow is evident in the lower levels. The winds average 5-10 knots from the surface through 15,000 feet and 15-25 knots between 20,000 and 30,000 feet. Above 30,000 feet, the wind speeds increase to 25-35 knots, which reflects the development of the tropical easterly jet (TEJ) over the Indian Ocean. The eastern limit of the TEJ is sometimes found over the western Pacific Ocean.

Southern Island Group. A steady east to southeasterly wind persists throughout the atmosphere. Wind speeds average 10-20 knots through 30,000 feet over the entire area. They are strongest during July and August.

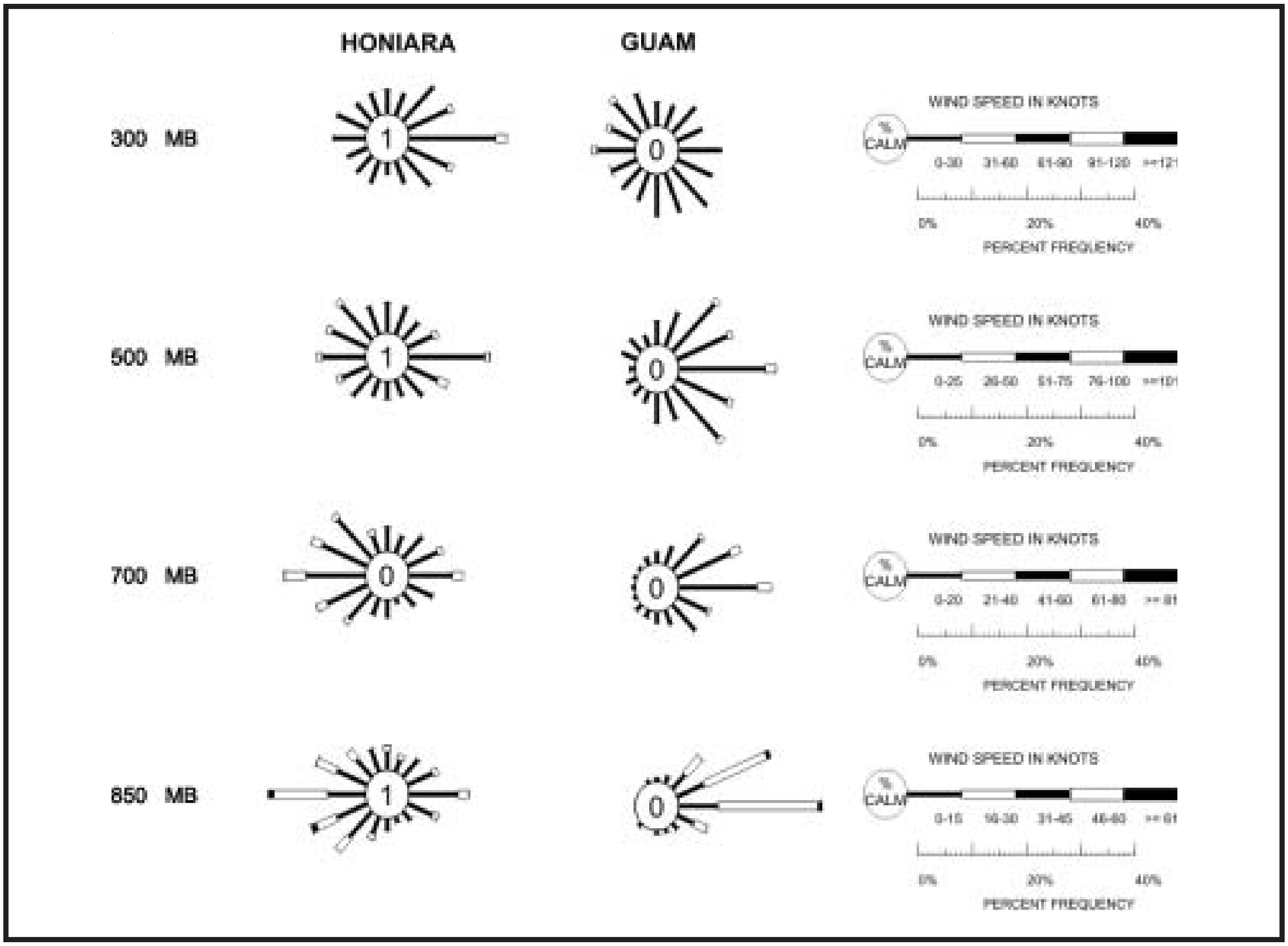

Figure 7-14. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 mb and 300 mb over .

Precipitation. Many of the islands in the region have mountainous terrain, so the amount of rainfall any one location gets depends upon the surrounding topography. Locations on windward sides of mountains will receive more rain than locations on leeward sides. Also, locations on the end of peninsulas away from the mountains, and exposed to the prevailing wind flow, will have less rainfall than locations closer to the mountains. Figures 7-15 and 7-16 show precipitation amounts and days for selected locations.

North Island Group. The area sees a significant increase in precipitation. Over 70 percent of the annual rainfall occurs during this season. Much of the increased rainfall is due to the NETWC; most falls in short, heavy showers. Several days with moderate to heavy, continuous rain are possible, especially when the islands are under a tropical cyclone feeder band. The southern islands get 20-25 days of precipitation a month, while the northern islands have 12-26 days. The mean monthly rainfall totals are 4-16 inches (100-400 mm). Extreme monthly minimums of under 1 inch (25 mm) of rain have been recorded. This reflects the drought potential of the islands, especially the year after an El Niño. High rainfalls are also possible; monthly totals have topped 35 inches (900 mm) at some sites. Twenty-four hour rainfall totals over 18 inches (450 mm) have occurred, usually with tropical cyclones. Thunderstorm activity increases during the wet season. On the average, 1-5 thunderstorm days occur each month. The southern islands see more activity because of the proximity of the NETWC. The thunderstorms cause local squalls with brief, heavy showers.

Central Island Group. The southwest monsoon is the rainy season for most of the islands. The only places that get less than 50 percent of their annual rainfall now lie near or south of 5° N. This is because the NETWC, along with most of the rainfall activity, lies north of these places for most of the southwest monsoon. Overall, the islands average 20-23 days of precipitation per month. Some places have as few as 10 rain days per month, while others get rain almost every day. Mean monthly rainfall totals range from as little as 5.50 inches (140 mm) per month to just over 18 inches (460 mm) per month. Generally, November is the driest month, and July is the wettest. The islands in the central part of the region have the most rain and the amount decreases to the north and south because the NETWC remains over the central part of the region most of the time. Some rainfall is also attributed to topography. Pohnpei, which has one of the greatest rainfall totals in the region, has significant terrain features. Orographic lifting there significantly contributes to the high rainfall totals. Drought can also affect the region, especially with an El Niño. Monthly rainfall totals below 5 inches (125 mm) have occurred. Kapingamarangi Atoll, the southernmost island in the area, had 1 month with no rain. On the other hand, very heavy rainfall is also possible as monthly rainfall totals have exceeded 45 inches (1150 mm) at some locations. These heavy rainfall totals are usually with a passing tropical cyclone or an extremely active NETWC.

Thunderstorms occur a little more frequently during the southwest monsoon; 1-5 thunderstorm days occur each month. The strong tradewind inversion that suppressed most of the thunderstorm activity during the northeast monsoon is virtually nonexistent. This allows convective activity to build, especially with the NETWC.

Southern Island Group. The area continues to get a lot of rainfall, but slightly less than in the northeast monsoon because the NETWC is out of the area. Still, the islands average almost 19 days of rain per month. A few have rain on a few as 8 days per month, while others have rain as many as 28 days per month. Mean monthly rainfall totals range from over 3 to just over 15 inches (75-380 mm). High totals are also possible as monthly and twenty-four hour rainfall totals have exceeded 36 inches (900 mm) and 10 inches (250 mm), respectively, at some locations, usually with heavy rain squalls.

Thunderstorm activity is also less than during the northeast monsoon, 3-6 thunderstorm days a month. Most activity takes place in the central and southern islands where some locations get up to 11 thunderstorm days a month. The thunderstorms mostly occur in the heat of the day (14L-16L) and late evening to overnight hours (21L-05L). The tradewind inversion that is present over the region during the morning hours tends to restrict thunderstorm development. When the thunderstorms do occur, tops to over 50,000 feet have been reported.

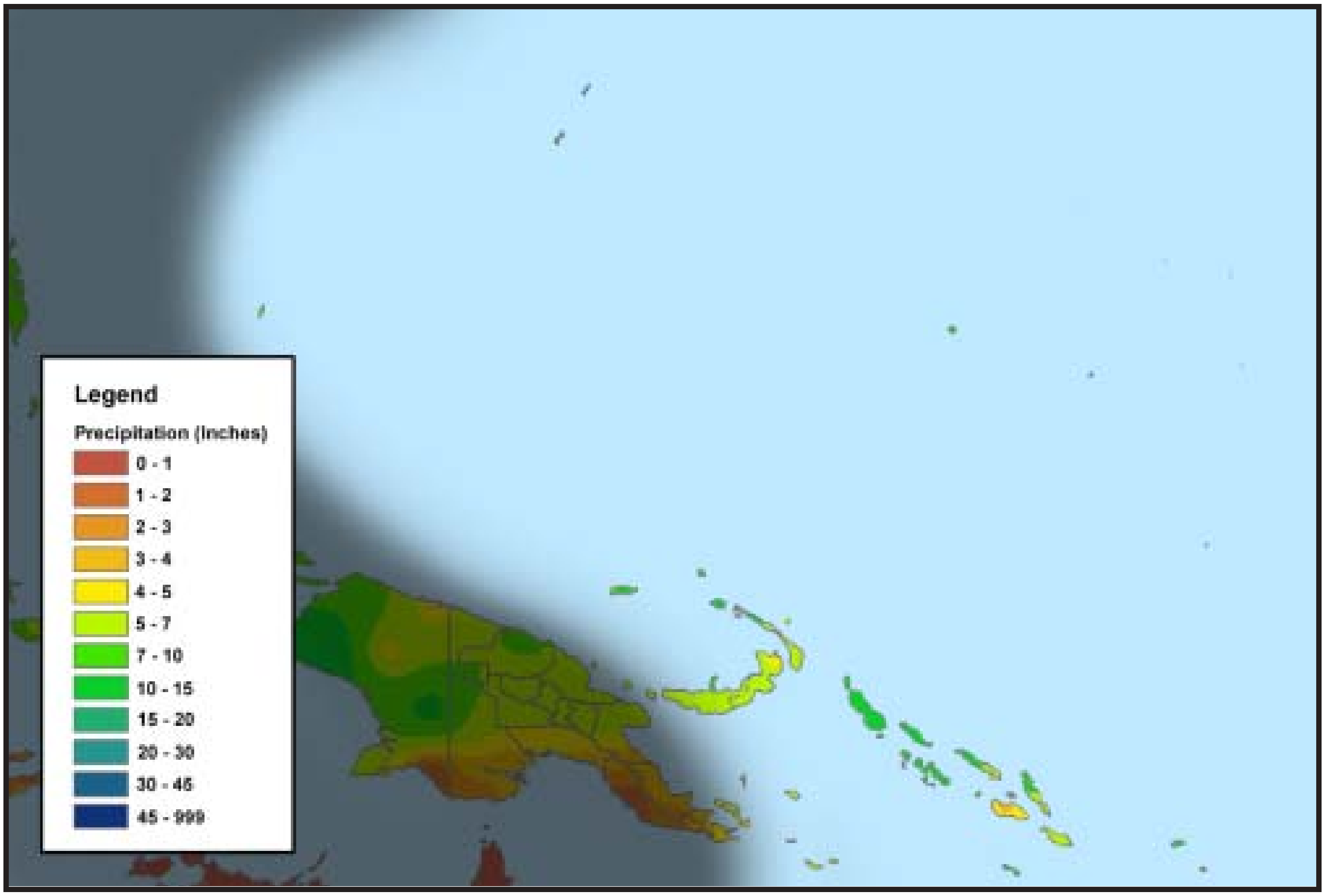

Figure 7-15. July Mean Precipitation. The figure shows mean precipitation in the region.

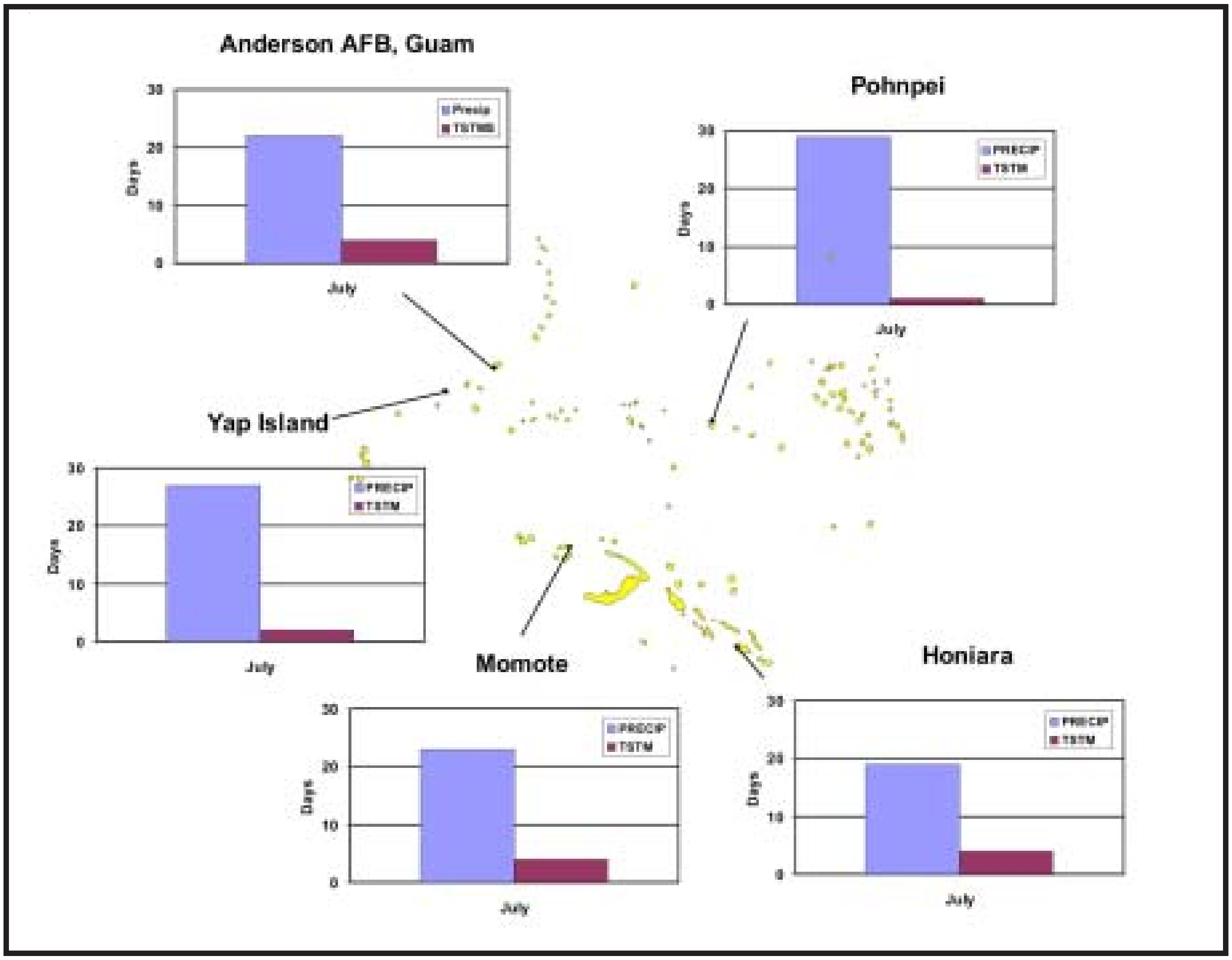

Figure 7-16. Southwest Monsoon Season Mean Rain and Thunderstorm Days. The graphs show the average seasonal occurrences of rain and thunderstorm days for representative locations in the region.

Temperatures. Figures 7-17 and 7-18 show mean high and low temperatures for selected locations.

North Island Group. Mean high temperatures range from 84° to 88°F (29° to 31°C), the mean lows from 75° to 79°F (23° to 26°C). The extreme high and low were 98° and 67°F (37° and 19°C).

Central Island Group. Temperatures remain stable. Mean high temperatures are 82° to 88°F (28° to 31°C), while the mean lows average 75° to 82°F (24° to 28°C). The extreme high and low were 102° and 66°F (39° and 19°C).

Southern Island Group. The temperature is stable, though some of the southeastern islands are slightly cooler due to the cooler southeasterly trades. Mean high temperatures range from 81° to 90°F (27° to 32°C), the mean lows range from 73° to 82°F (23° to 28°C). The extreme high and low were 106° and 64°F (41° and 18°C).

Figure 7-17. July Mean Maximum Temperatures (°C). Mean maximum temperatures represent the average of all high temperatures for the warmest month of the southwest monsoon season. Daily high temperatures are often higher than the mean.

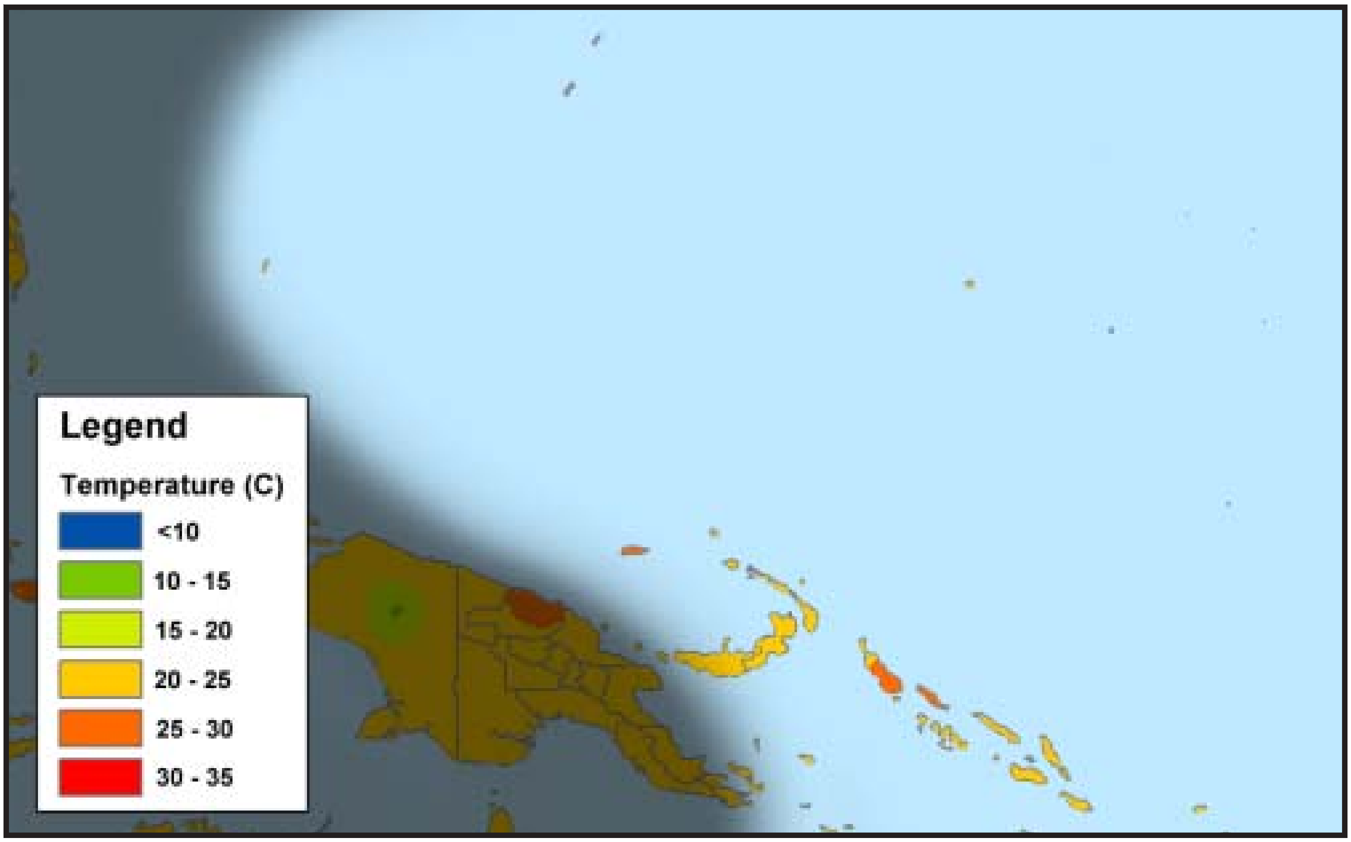

Figure 7-18. July Mean Minimum Temperatures (°C). Mean minimum temperatures represent the average of all low temperatures for the warmest month of the southwest monsoon season. Daily low temperatures are often lower than the mean.

Hazards. Light-to-moderate turbulence occurs over the terrain of some of the high islands. Some of the turbulence is thermally induced, but most is caused by the winds interacting with the terrain. Light-to-moderate mixed icing can occur above 15,000 feet. Severe mixed icing and turbulence occur in the vicinity of thunderstorms. Icing is confined to heights above 15,000 feet, while the turbulence can occur at any level. Tropical cyclones bring a range of hazards. Wind gusts over 100 knots are possible. Extremely heavy rainfall will cause flooding, while the storm surges cause serious damage in the coastal areas and can overrun low-lying atolls. Very heavy surf can extensively damage or completely destroy coastal structures.

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